University of Zagreb

FACULTY OF KINESIOLOGY

Andro Štefan

THE EFFECTS OF WEARING STANDARD POLICE EQUIPMENT ON THE INCREASED OCCURRENCE OF ASYMMETRY IN WALKING AND STANDING IN BASIC POLICE APPLICANTS OF THE MINISTRY OF INTERNAL AFFAIRS OF THE REPUBLIC OF CROATIA

DOCTORAL THESIS

Zagreb, 2024.

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Supervisor:

prof. Mario Kasović, Ph.D.

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DOKTORSKI RAD

Mentor:

prof. dr. sc. Mario Kasović

Zagreb, 2024.

TALE OF CONTENTS:

1. DECLARATIONS

I, Andro Štefan, hereby declare that this dissertation entitled “The effects of wearing standard police equipment on the increased occurrence of asymmetry in walking and standing in basic police applicants of the Ministry of Internal affairs of the Republic of Croatia” is my original work, and that it does not contain any material previously written or published by me or any other person, apart from the published articles presented in Chapter 3. In the thesis, I have acknowledged assistance that I had received in this work, and I have presented all relevant sources of information.

This doctoral research is comprised of three studies with interconnected research aims. The studies resulted in three scientific articles published in international peer-reviewed journals that are included in this thesis. All three articles were published after my enrolment in the doctoral programme.

In the thesis, I used the American Psychological Association (APA) 7th edition style of referencing. References from all chapters are presented alphabetically in the “References” chapter.

All three studies were conducted in accordance with the Declaration of Helsinki. In addition, all participants provided written informed consent to participate in the study. This study was approved by the Ministry of the Interior and Police Academy "Josip Jovic" and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethics code number: 511-01-128 -23-1)

2. SUPERVISOR INFORMATION

Mario Kasović was born on June 18, 1970. in Zagreb (Croatia). He is a full professor at the Faculty of Kinesiology at the University of Zagreb. The academic degree of Doctor of Science in the field of social sciences, the field of educational sciences - branch of kinesiology, he obtained by defending his doctoral dissertation on March 4, 2009, entitled "Biomechanical assessment of anterior cruciate ligament reconstruction".

In January 2001, he was appointed as a researcher on the project "Neuromuscular biomechanical diagnosis of sports and pathological locomotion" led by Prof. Ph.D. Vladimir Medved and to the Biomechanics course at the University Undergraduate Studies of the Faculty of Kinesiology in Zagreb, where he participates in teaching. By the time of registration, he had published 46 scientific papers published in scientific journals, in their entirety in proceedings, in the form of summaries in conference proceedings, and 58 professional papers published in proceedings and journals.

He was awarded the Rector's Prize in 1997 for his scientific work entitled "Laboratory neuro-muscular test of reflective abilities of alpine skiers". In December 2006, he received recognition for the most successful scientific novice - assistant in the academic year 2005/2006. at the Faculty of Kinesiology, University of Zagreb. He is an active triathlon coach at the Maksimir Triathlon Club.

He is a member of many international and domestic scientific and professional associations such as the International Society of Biomechanics (ISB), The American Senior Fitness Association (SFA), the Croatian Association of Kinesiologists, the Croatian Society for Osteoporosis, the Croatian Society for the Prevention of Obesity, the Croatian Association of Teachers and Trainers skiing and the VitaSport Sports Recreation Association from Zagreb.

3. ACKNOWLEDGMENT

Professor Kasović, thank you for being my guide and support through all the challenges. Your insight, experience and patience helped me overcome obstacles and become a better version of myself, both professionally and personally.

Mom and Dad, your love and support have followed me throughout my life. You taught me the values of work, persistence and honesty, and your beliefs in me gave me the strength to keep going, even when it was the most difficult.

Lovro, thank you very much! Your brotherly support was irreplaceable. You were always there for me; you were my support and motivation. You knew how to cheer me up, both when I was at the top and when it was the hardest. Your example was an inspiration to me.

Last, but certainly not least, to my beloved Lora - you are my light and strength. Your unconditional love, understanding and support are what carried me through all the challenges. Thank you for believing in me and for always being with me, at every moment.

I would also like to express my special gratitude to the committee members. Thank you for taking the time to review my work, for your helpful advice and constructive feedback. Your professional insight was invaluable in shaping my project. Without your efforts and support, this process would not be possible, and I am extremely grateful for your involvement.

What I have achieved is not only my success, but ours together. You all gave me a part of yourself, and I will forever be grateful for everything you have done for me.

With respect,

Andro Štefan

4. LIST OF ABBREVIATIONS

- SPSS Inc., Chicago, IL, USA - Statistical Packages for Social Sciences software version 23
- SD - standard deviation
- ES - effect size

5. ABSTRACT

Aim The main objective of this doctoral thesis is to determine if standard police equipment affects the increase in walking and standing asymmetry. Regarding the primary objective, three specific objectives were established for three independent studies (**Study 1, Study 2 and Study 3**). ***Study 1*** aims to assess whether standard police equipment affects the increase in asymmetry in the spatio-temporal parameters of the basic gait of police officers. ***Study 2*** aimed to assess whether the standard police equipment affects the increase in the asymmetry of the forces and the pressures under the front, the middle and the back of the foot of the basic police. ***Study 3*** aims to evaluate whether the standard police equipment affects the increased display of asymmetry during the stay of the basic police.

Study 1 methods In this cross-sectional study, we recruited police recruits who were part of a one-year academy training program intended to become part of the Croatian police service. Typically, a police academy recruits between 750 and 1000 people each year. 900 police recruits were screened and selected to participate in the study. The inclusion criteria strictly stipulate that all participants must be free of acute or chronic locomotor and mental diseases, which could prevent them from participating in the study. Exclusion criteria included participants suffering from locomotor disease (injury) or mental illness (depression or other illness) and who were ill at the time of the study. To analyse the spatial parameters of gait, we used the Zebris pedobarographic platform (FDM; GmbH, Munich, Germany). This advanced device includes 11,264 sensors with a sampling rate of 100 Hz and a sensor area of 149 cm × 54.2 cm. Its main function is to capture, process and produce gait characteristics in dynamic (lying) and static (resting) conditions. All procedures were anonymous and compliant in the Declaration of Helsinki. In addition, all participants provided written informed consent to participate in the study. This study was approved by the Ministry of the Interior and Police Academy "Josip Jovic" and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethics code number: 511-01-128 -23-1).

Study 1 results Compared to the “no load” condition, a standardized load of 3.5 kg/7.5 kg/10 kg was administered. A load of 7 lb significantly increased asymmetries in the spatial parameters of gait, as follows: heavy gait phases (mean difference = 1.05), load response (mean difference = 0.31), single member support (mean difference = 0.31), single limb support (mean diff. = 0.56), pre-swing (average change = 0.22) and swing (average change = 0. 90), while no significant asymmetry was observed in leg rotation, step length and stride length. For gait time

parameters, we observed a significant asymmetry in stride time (mean difference = -0.01), while no difference was observed in walking cadence and speed.

Study 1 conclusions Results indicate that the additional fee of 3. 5 kg / 7.7 lb are more likely to increase the asymmetries in the spatial components of the gait cycle, compared to the temporal parameters. Thus, external policing can have dangerous effects by increasing the general asymmetry of the body, which can lead to a higher risk of injury and reduced performance to perform specific daily tasks.

Study 2 method The sample of respondents for **Study 2** was determined in **Study 1** (see detailed information in **Study 1**). The absolute values of ground reaction forces and plantar pressures under different regions of the foot were evaluated with a pedobarographic platform (Zebris FDM). Skewness was calculated as (xright - xleft) / 0.5 × (xright + xleft) × 100%, where the term "x" denotes a specific parameterbeing computed, and if it is closer to 0, the value of x is more reflective.

Study 2 results Significant differences in ground reaction forces and plantar pressures between the left and right foot were observed when a "3.5 kg load" was added. Compared to the “no load” condition, carrying a “3.5 kg load” resulted in an increase in ground reaction force and plantar pressure. The load of 3.5 kg significantly increased the gait asymmetries for the peak ground reaction forces under the forefoot (ES = 0.29), midfoot (ES = 0) and hindfoot (ES = 0, 19) regions). For plantar pressure peaks, only the asymmetry under the midfoot region increased significantly (ES = 0.19).

Study 2 conclusion The results of this study show that a "3.5 kg load" significantly increases the ground reaction force and the asymmetry of the forefoot and midfoot pressure compared to the condition " without charge". Due to higher loads, increased kinetic gait asymmetry may have negative effects on future pain and discomfort in the leg region, possibly causing stress fractures and deviant gait biomechanics in police recruits.

Study 3 method The sample of respondents for **Study 3** was determined in **Study 1** (see detailed information in **Study 1**). The characteristics of the leg in a standing position were assessed with the Zebris FDM pedobarographic pressure platform.

Study 3 results Carrying a load of 3.5 kg significantly increased the area of the 95% confidence ellipse (Δ = 15.0%, $p = 0.009$), the path length of the centre of pressure (Δ = 3.3%, $p = 0.009$). 023) and the average speed (Δ = 11.1%, $p = 0.014$), the length of the minor axis (Δ = 8.2%, $p < 0.009$) and the deviation in X (Δ = 12.4%, $p = 0.005$) and Y (Δ = 50.0%, $p < 0.001$). For ground reaction forces, a significant increase in the front of the left leg (Δ = 2.0%, $p < 0.001$). 0%, $p = 0.002$) and decreases were observed in the left rear leg (Δ = -2.0%, $p = 0.002$). No significant difference was observed in the relative ground reaction forces under the anterior and posterior regions for the right leg ($p>0.002$). 05).

Study 3 conclusions The results of suggest that the spatial and temporal parameters of the foot may be more sensitive to change during the transport of heavy loads, especially the characteristics of the centre of pressure.

Key words: special populations; police equipment; load carriage; symmetry; effect size; foot characteristics; centre of pressure; statics; changes

6. SAŽETAK

Cilj Glavni cilj ovog doktorskog rada je utvrditi utječe li standardna policijska oprema na povećanje asimetrije hodanja i stajanja. Što se tiče primarnog cilja, utvrđena su tri specifična cilja za tri neovisne studije (***Studija 1***, ***Studija 2*** i ***Studija 3***). ***Studija 1*** ima za cilj procijeniti utječe li standardna policijska oprema na povećanje asimetrije u prostorno-vremenskim parametrima osnovnog hoda policijskih službenika. ***Studija 2*** imala je za cilj procijeniti utječe li standardna policijska oprema na povećanje asimetrije sila i pritisaka ispod prednjeg, srednjeg i stražnjeg dijela stopala temeljne policije. ***Studija 3*** ima za cilj utvrditi utječe li standardna policijska oprema na pojačanu pojavu asimetrije tijekom stajanja službenika temeljne policije.

Metode Studije 1 U ovoj presječnoj studiji regrutirali smo policijske novake koji su bili dio jednogodišnjeg programa obuke u akademiji s namjerom da postanu dio hrvatske policijske službe. Obično policijska akademija svake godine regrutira između 750 i 1000 ljudi. 900 policijskih novaka pregledano je i odabrano za sudjelovanje u studiji. Kriteriji uključivanja strogo propisuju da svi sudionici ne smiju imati akutne ili kronične lokomotorne i psihičke bolesti koje bi ih mogle spriječiti u sudjelovanju u istraživanju. Kriteriji za isključenje podrazumijevali su sudionike koji pate od bolesti lokomotornog sustava (ozljeda) ili mentalne bolesti (depresija ili druga bolest) i koji su bili bolesni u vrijeme istraživanja. Za analizu prostornih parametara hoda koristili smo pedobarografsku platformu Zebris (FDM; GmbH, München, Njemačka). Ovaj uređaj uključuje 11.264 senzora s brzinom uzorkovanja od 100 Hz i površinom senzora od 149 cm × 54.2 cm. Njegova glavna funkcija je prikupljanje, obrada i opis karakteristika hoda u dinamičkim (kretački) i statičkim (mirujući) uvjetima. Svi postupci bili su anonimni i u skladu s Helsinškom deklaracijom. Osim toga, svi su sudionici dali pisani informirani pristanak za sudjelovanje u studiji. Studiju su odobrili Ministarstvo unutarnjih poslova i Policijska akademija "Josip Jović" i Etičko povjerenstvo Kineziološkog fakulteta Sveučilišta u Zagrebu, Hrvatska (etički kod broj: 511-01-128 -23-1).

Rezultati studije 1 U usporedbi sa stanjem "bez opterećenja", primijenjeno je standardizirano opterećenje od 3.5 kg/7.5 kg/10 kg. Opterećenje od 7 lb značajno je povećalo asimetrije u prostornim parametrima hoda, kako slijedi: faze pojačanog hoda (srednja razlika = 1.05), odgovor na opterećenje (srednja razlika = 0.31), faza potpore jednog ekstremiteta (srednja razlika = 0.31), faza potpore jedne noge (srednja razlika = 0.56), predzamah (prosječna promjena = 0.22) i faza zamaha (prosječna promjena = 0.90), dok nije zabilježena značajna asimetrija u rotaciji donjeg ekstremiteta, duljina koraka i duljina dvokoraka. Za parametre vremena hoda, uočili smo značajnu asimetriju u vremenu koraka (srednja razlika = -0.01), dok nije primijećena razlika u kadenci i brzini hoda.

Zaključci studije 1. Rezultati pokazuju da dodatno opterećenje od 3,5 kg / 7,7 lb vjerojatnije povećava asimetrije u prostornim komponentama ciklusa hoda u usporedbi s vremenskim parametrima. Vanjsko opterećenje može imati negativne učinke povećanjem ukupne asimetrije tijela, što može dovesti do povećanog rizika ozljeda te smanjene sposobnosti za obavljanje specifičnih svakodnevnih zadataka.

Metoda Studije 2 Uzorak ispitanika za **Studiju 2** određen je u **Studiji 1** (pogledajte detaljne informacije u ***Studiji 1***). Apsolutne vrijednosti sila reakcije podloge i plantarnih pritisaka pod različitim regijama stopala opisane su pedobarografskom platformom (Zebris FDM). Asimetrija je izračunata prema formuli (xdesno - xlijevo) / 0.5 × (xdesno + xlijevo) × 100%, pri čemu pojam "x" označava specifičan parametar koji se računa, a što je vrijednost bliža 0, to je parameter više stvaran.

Rezultati studije 2 Značajne razlike u silama reakcije podloge i plantarnom pritisku između lijevog i desnog stopala zabilježene su pri dodatku opterećenja od 3,5 kg. U usporedbi sa stanjem bez opterećenja, nošenje opterećenja od 3,5 kg rezultiralo je povećanjem sila reakcije podloge i plantarnog pritiska. Opterećenje od 3,5 kg značajno je povećalo asimetrije hoda u vršnim silama reakcije podloge ispod prednjeg dijela stopala (ES = 0,29), srednjeg dijela stopala (ES = 0) i stražnjeg dijela stopala (ES = 0,19). Što se tiče vršnih vrijednosti plantarnog pritiska, značajno je porasla samo asimetrija ispod srednjeg dijela stopala (ES = 0,19).

Zaključak studije 2 Rezultati ove studije pokazuju da opterećenje od 3,5 kg značajno povećava sile reakcije podloge te asimetriju pritiska prednjeg i srednjeg dijela stopala u usporedbi sa stanjem bez opterećenja. Zbog većih opterećenja, povećana kinetička asimetrija hoda može imati negativne učinke na pojavu bolove i nelagodu u području donjih ekstremiteta, potencijalno uzrokujući stres frakture i odstupanja u biomehanici hoda kod novih policijskih službenika.

Metoda Studije 3 Uzorak ispitanika za **Studiju 3** određen je u **Studiji 1** (pogledajte detaljne informacije u **Studiji 1**). Karakteristike nogu u stojećem položaju procijenjene su pomoću pedobarografske platforme Zebris FDM za mjerenje pritiska.

Rezultati studije 3 Nošenje opterećenja od 3,5 kg značajno je povećalo površinu 95%-tnog intervala pouzdanosti elipse (Δ = 15,0%, p = 0,009), duljinu puta središta pritiska (Δ = 3,3%, p = 0,023) i prosječnu brzinu (Δ = 11,1%, p = 0,014), duljinu manje osi (Δ = 8,2%, p < 0,009) te odstupanja u smjeru X (Δ = 12,4%, p = 0,005) i Y (Δ = 50,0%, p < 0,001). U pogledu sila reakcija podloge, zabilježen je značajan porast u prednjem dijelu lijeve noge (Δ = 2,0%, p < 0,001) te pad u stražnjem dijelu lijeve noge (Δ = -2,0%, p = 0,002). Nije zabilježena značajna razlika u relativnim silama rekacije podloge ispod prednjeg i stražnjeg dijela desne noge (p > 0,005).

Zaključci Studije 3 Rezultati sugeriraju da prostorni i vremenski parametri stopala mogu biti osjetljiviji na promjene tijekom prenošenja tereta, osobito karakteristike središta pritiska.

Ključne riječi: posebne populacije; policijska oprema; teretna kočija; simetrija; veličina učinka; karakteristike stopala; centar pritiska; statika; promjene

7. INTRODUCTION

7.1. Context and Literary review

The use of standard equipment is one of the main components of physical activity in special populations, such as law enforcement officers (Larsen et al., 2016). Due to the specificity of the profession, which involves carrying out and performing police work at the maximum level, most of the movement patterns of police officers are performed by running, jumping/jumping and carrying loads heavy (Lockie et al). It has been found that police officers can carry loads ranging from 10% to 40% of their body weight (Carlton et al., 2016), leading to lower levels and unprofitable performance. In addition, the use of standard equipment for 8 to 12 hours of work can be one of the main causes of the reduction of the efficiency and function of the foot during walking and standing (Scott et al, 2007) . Since the first contact of the body with the ground is through the foot, it represents an essential link in the kinetic chain of the body, absorbing external forces.and now the forward movement of the body (Saltzman and Nawoczenski, 1995). When an individual wears standard equipment, it changes its normal structure and movement pattern, which mainly results in an increase in asymmetry between the left and right sides of the body (Zhang et al., 2010 Majumdar et al. , 2010; , 1991; Shi et al. , 2015). The appearance of increased asymmetry in gait is one of the main negative characteristics of the use of standard devices in specific populations (Park et al., 2018; Majumdar et al., 2010; Majumdar et al. French, 2013).

Although the literature often indicates that a healthy or natural gait is symmetrical (Seeley et al., 2008) and the normal distance between the two sides of the body can be between 5% and 15% (Lanshammar and Ribom, 2011) , previous research. showed that the additional load on the already existing gait asymmetry can also increase the difference between the right and left sides of the body by up to 50% (Zhang et al., 2010). Most previous research has been conducted on specific police populations (Kasović et al. , 2020; Larsen et al. , 2016) is the army (Walsh and Low, 2021; Coombes and Kingswell, 2005; Fellin et al., 2016; Majumdar et al., 2010; Majumdar et al., 2013; Schulze et al., 2013. , 2014) studied the effects of maintaining different equipment weights changes in the spatio-temporal and kinetic parameters of walking.

For example, research in service police officers showed that standard police clothing resulted in a significant reduction in the length of two steps, while there was no change in walking speed, width of the step and the number of steps per minute (Ramstrand et al., 2016).). On the other hand, the research of Lewinsky et al. (2015) showed how walking speed and acceleration decrease when wearing extra gear.

A recent study conducted on of Croatian police recruits showed that wearing police gear can cause greater leg rotation, shortening of strides and two-steps, and stride width, as well as increases in the length of strides, two steps, and decreases in speed and number. of steps per minute (Kasović et al., 2020). The same research showed a significant increase in peak pressures under certain leg regions when wearing standard police clothing. Walsh's synthetic work and Low (2021), who was based mainly on members of the military population, concluded that, in a sample of 20 studies, the use of additional equipment did not have a significant effect on the changes in the parameters of the spatiotemporal gait movements, while the values of the base and plantar pressure reaction forces increased significantly. In addition to the research mentioned above, which led to conflicting results on some spatio-temporal parameters of gait while wearing standard equipment, a relatively small number of studies have tried to answer the question of whether the use of l Standard equipment leads to an increase in performance. of asymmetry in dynamic (walking) and static (resting) conditions.

In a study conducted on firefighters, the results showed that there is a significant increase in the occurrence of asymmetry during walking when a load is carried on the right shoulder, with the right leg taking longer steps compared to the left leg (Park et. al., 2018). One-sided loading, which is one of the main ones characteristics of the police equipment, has been found to be a factor that reduces the duration of the gait cycle and increases the time in the double support phase (both feet are simultaneously on the ground) (Crowe et al., 1993). Unilateral devices have also been shown to cause more negative compensations, compared to bilateral devices, in terms of greater forces and pressures generated under the foot where the load is greater (Marras and Granata, 1997; 2010), and tilting the body towards the side not affected by the external load (Matsuo et al., 2008).

Although the studies cited above have examined the effects of external loading on gait biomechanics in specific populations, most research has been conducted on service members with varying levels of task loading (Walsh and Low, 2021), and only a few studies have examined the effects. of standard equipment on gait asymmetry (Park et al., 2018; Crowe et al., 1993) in a relatively small sample of respondents, while the field of statics, which is e. stationary, not studied. It was also found that there are no studies that have simultaneously investigated the spatial and kinetic parameters of walking and standing, with respect to the standard equipment of basic police recruits. Since a previous study found small but significant effects between the biomechanics of walking without and with police equipment (Kasović et al., 2020), it is reasonable to assume that the use of additional standard police equipment will also increase the aspect of one. asymmetry between left and right leg characteristics during walking and standing in space-time and kinetic parameters.

7.2. Lists of tables

7.3 Research aims and questions

The main goal of this doctoral dissertation is to determine whether standard police equipment affects the increased occurrence of asymmetry in walking and standing.

Regarding the main goal, the following sub-goals were generated:

1. to determine whether standard police equipment affects the increased occurrence of asymmetry in the spatio-temporal parameters of the gait of basic police officers;
2. to determine whether standard police equipment affects the increased occurrence of asymmetry of forces and pressures under the front, middle and rear part of the foot in the entrance of the basic police;
3. determine whether standard police equipment affects the increased occurrence of asymmetry during quiet standing at the entrance of the basic police.

The main research hypotheses are:

1. standard police equipment weighing 3.5 kg will significantly affect the increased occurrence of asymmetry in the spatio-temporal parameters of the gait of basic police officers;
2. standard police equipment weighing 3.5 kg will significantly affect the increased occurrence of asymmetry of forces and pressures under the front, middle and rear part of the foot in the entrance of the basic police;
3. standard police equipment weighing 3.5 kg will significantly affect the increased occurrence of asymmetry of relative forces under the front and back part of the foot during quiet standing at the entrance of the basic police.

7.4. List of research studies

To answer the questions, this thesis includes three studies. All studies were published in peer-reviewed international journals. The studies are listed according to the date of submission:

1. Štefan, A., Kasović, M., & Štefan, L. (2024). Does a Standardized Load Carriage Increase Spatiotemporal Gait Asymmetries in Police Recruits? A Population-based Study. *Military medicine*, usae358. Advance online publication. https://doi.org/10.1093/milmed/usae358

2. Kasović, M, Štefan, A., & Štefan, L. (2024). Carrying Police Load Increases Gait Asymmetry in Ground Reaction Forces and Plantar Pressures Beneath Different Foot Regions in a Large Sample of Police Recruits. *Bioengineering*, *11*(9), 895. https://doi.org/10.3390/bioengineering11090895

3. Štefan, A., Kasović, M., & Štefan. L., (2024). Load Carriage and Changes in Spatiotemporal and Kinetic Biomechanical Foot Parameters during Quiet Stance in a Large Sample of Police Recruits. *Applied Sciences*, *14*(8), 3274. https://doi.org/10.3390/app14083274

7.5. Thesis outline

Chapter one introduces the thesis and an overview of literature review.

Chapter two presents the research studies included in this thesis. First study aims to assess whether standard police equipment affects the increase in asymmetry in the spatio-temporal parameters of the basic gait of police officers. The second study aims to assess whether the standard police equipment affects the increase in the asymmetry of the forces and the pressures under the front, the middle and the back of the foot at the entrance of the basic police. The third study aims to evaluate whether the standard police equipment affects the increased display of asymmetry during the stay in the entrance of the basic police.

Chapter three makes a conclusion to the dissertation by summarizing each of the three presented papers. Also, we included the conclusion of each paper and describe their mutual relation, the strengths and limitations of the study and possible directions for future research and practice.

8. RESEARCH METODOLOGY

8.1. Study population

In this cross-sectional study, we studied applicants to the Croatian Police Academy. Every year, the Police Academy receives about 750 men and women from all over Croatia for a one-year training program. Upon completion of the program, they become part of the Croatian police system and are trained to perform police duties and functions. 900 police recruits were screened and selected to participate in the study.

Before conducting the test, none of the subjects before or during the test should have had acute or chronic diseases of the locomotor system or mental disorders, or injuries that could affect the result of the measurement or make it impossible to carry it out. Before starting the research, all respondents received information about the research objectives, hypotheses, advantages and possible risks.

The research was conducted anonymously and in accordance with the Declaration of Helsinki, which guarantees anonymity and protection of personal data. Also, before starting the research, we requested approval to enter the research from the Ethics Committee of the Josip Jović Police School (Ethical Code: 2023-2024). Each subject had to give written and informed consent to participate in the research.

8.2. Study variables

Study 1

In study 1, the spatial gait parameters that were analysed were: 1) foot rotation (external/internal) expressed in degrees, 2) step length (length between the heel of the right foot and the heel of the left foot) expressed in centimetres, 3) length of two steps (length from the heel of the right foot) to the heel of the second right foot) expressed in centimetres, 4) step width (width between two feet) expressed in centimetres and 5) phases of the left and right feet during walking in the standing phase, load transfer over one leg, intermediate phase, the pre-swing phase, the swing phase and the two-support phase expressed in percentages of the gait cycle.

The time parameters of the analysis of walking were: 1) time required for a step left and right expressed in seconds, 2) time of two steps expressed in seconds, 3) cadence (number of steps per minute) and 4) walking speed expressed in meters. per second (m/s). The values of foot rotation, length of step and two-step, width of step, time of step and two-step, cadence and walking speed were expressed on a numerical measuring scale, while phases or cycles of walking were expressed in percentage (%).

We calculated the symmetry index according to the following formula (Robinson et al., 1987): (Xright – Xlliva)/0.5*(Xright + Xlliva) *100%, where the result 0 indicates complete symmetry between the right and left sides of the body.

Study 2

Regarding the second hypothesis, the kinetic parameters of the gait analysis were: 1) maximum forces under the forefoot, midfoot and hindfoot of both feet expressed in newtons (N) and 2) maximum pressures under the forefoot, midfoot and rearfoot of both feet expressed in newtons per surface area (N/cm2).

Forces and pressures under the forefoot, midfoot, and rearfoot are generated on a numerical measurement scale. We calculated the symmetry index according to the following formula (Robinson et al., 1987): (Xright – Xlliva)/0.5*(Xright + Xlliva) *100%, where the result 0 indicates complete symmetry between the right and left sides of the body.

Study 3

Each subject was tested in two conditions (without equipment and with standard police equipment). The static variables used for the analysis are: 1) the position of the centre of pressure of the left and right legs, 2) the speed of the centre of pressure expressed in millimetres per second (mm/s), the area of the x and y axes (coordinate system enclosed by the toes and heels, and their position is determined based on this), 3) absolute values of the forces of both feet, and analysis of the forces of the front and rear parts of the feet and 4) relative forces of the front and rear parts of both feet expressed in percentage (%).

The position of the centre of pressure of the left and right leg, the speed of the centre of pressure, the area of the x and y axes, and the absolute values of the forces were expressed on a numerical scale, while the relative forces under the front and back of the left and right feet were expressed in percentages.

Forces and pressures under the forefoot, midfoot, and rearfoot were generated on a numerical scale. We calculated the symmetry index according to the following formula (Robinson et al., 1987): (Xright – Xlliva)/0.5*(Xright + Xlliva) *100%, where the result 0 indicates complete symmetry between the right and left sides of the body.

8.3. Testing Procedures

Study 1

At the meter's signal, the subject will walk barefoot on the platform (looking forward, normal arm swing, natural walking speed) 6 times. Before starting the measurement, the subject will stand at the starting position 4.5 m before the platform and walk towards it and across it and will continue to walk 4.5 m in the other direction, until he reaches the mark where he should stop.

After that, the subjects will turn 180° and repeat the procedure to the starting position 5 more times. After testing, Zebris software will calculate the space-time parameters. Each respondent will be tested twice; the first attempt will be tested without equipment and after that with equipment.

Study 2

At the meter's signal, the subject will walk barefoot on the platform (looking forward, normal arm swing, natural walking speed) 6 times. Before starting the measurement, the subject will stand at the starting position 4.5 m before the platform and walk towards it and across it and will continue to walk 4.5 m in the other direction, until he reaches the mark where he should stop.

After that, the subjects will turn 180° and repeat the procedure to the starting position 5 more times. After testing, Zebris software will calculate the space-time parameters. Each respondent will be tested twice; the first attempt will be tested without equipment and after that with equipment.

Study 3

At the meter's signal, the subject stood on the platform in his natural position (stride position, arms relaxed by the body, gaze directed forward, normal breathing), and kept the upright body position for 15 seconds. After 15 seconds and at the meter's signal, the subject moved from the platform, and the software package Zebris analysed the data while standing still.

8.4. Data processing

We described the basic descriptive parameters with the arithmetic mean and standard deviation for normally distributed and median variables, and for non-normally distributed variables we used the Wilcoxon test. We calculated the normality of the distribution using the Kolmogorov-Smirnov test.

To determine significant differences between spatiotemporal biomechanical gait parameters without equipment and with official police equipment, we used Student's t-test for repeated measurements.

Cohen D (Cohen, 1981) was used to determine the size of the effects between the asymmetry in spatio-temporal parameters with the following values: 1) 0.2 - 0.5 - small, 2) 0.5 - 0.8 - medium and 3) >0.8 large effect size, and for the effect size of categorical variables we used the Cramer V association measure.

We also calculated the coefficient of variation expressed in percentages, as well as the internal consistency for each variable and between each measurement attempt on the platform where we used the intraclass correlation coefficient (ICC).

We set statistical significance at $p<0.05$. All analysis in this research were done in the statistical package SPSS version 24 (IBM, Chicago: II, USA).

9. ORIGINAL STUDIES

9.1. REASEARCH STUDY ONE

Article title

Does a Standardized Load Carriage Increase Spatiotemporal Gait Asymmetries in Police Recruits? A Population-based Study

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9.2. ABSTRACT

Introduction

Although the effects of carrying loads on gait biomechanics have been well-documented, to date little evidence has been provided whether such loads may impact spatial and temporal gait asymmetries under the different foot regions. Therefore, the main purpose of the study was to examine the effects of carrying standardized police equipment on spatiotemporal gait parameters.

Materials and Methods

In this population-based study, participants were 845 first year police recruits (age: 21.2 ± 2.3 years; height: 178.1 ± 10.2 cm; weight: 78.4 ± 11.3 kg; body mass index: 24.7 ± 3.2 kg/m^2; 609 men and 236 women; 72.1% men and 27.9% women) measured in two conditions: i) 'no load' and ii) 'a 3.5 kg load'. Spatiotemporal gait parameters were derived from the FDM Zebris pressure platform. Asymmetry was calculated as $(x_{right} – x_{left})/0.5*(x_{right} + x_{left})$ *100%,
where 'x' represented a given parameter being calculated and a value closer to 0 denoted greater symmetry.

Results

When compared to 'no load' condition, a standardized 3.5 kg/7.7 lb load significantly increased asymmetries in spatial gait parameters as follows: gait phases of stance (mean diff. = 1.05), load response (mean diff. = 0.31), single limb support (mean diff. = 0.56), pre-swing (mean diff. = 0.22), and swing (mean diff. = 0.90) phase, while no significant asymmetries in foot rotation, step and stride length were observed. For temporal gait parameters, we observed significant asymmetries in step time (mean diff. = -0.01), while no differences in cadence and gait speed were shown.

Conclusions

The findings indicate that the additional load of 3.5 kg/7.7 lb is more likely to increase asymmetries in spatial gait cycle components, opposed to temporal parameters. Thus, external police load may

have hazardous effects in increasing overall body asymmetry, which may lead to a higher injury risk and a decreased performance for completing specific everyday tasks.

9.3. Introduction

Carrying an external load during everyday tasks represents a major component of physical activity of police officers (Larsen et al., 2016). Although such load may be crucial for protection and high-level performance (Boffey et al., 2019), an intercorrelation between an individual, load and specific field-based duties may be considered to interact and affect one's health and well-being (Salvendy, 2012). A two-way approach of investigating the effects of load carriage on health status has often been proposed, focusing on physiological (Boffey et al., 2019; Faghy et al., 2022) and biomechanical changes (Boffey et al., 2019; Walsh & Low, 2021). In physiological studies, the load carried and speed of the march have been primarily responsible for energy expenditure changes (Boffey et al., 2019), while in the field of biomechanics, heavy load increases trunk, hip and knee flexion and hip and knee extension moments, while limited effects on spatiotemporal and kinetic gait parameters are observed (Walsh & Low, 2021).

Naturally, differences in bilateral behavior, often referred as 'body asymmetry', have risen a great attention in recent years (Seelay et al., 2008; Lanshammar & Ribom, 2011; Shi et al., 2015; Park et al., 2015). Although a healthy asymmetry between 5-15% has been identified as the upper threshold for adequate strength performance (Lanshammar & Ribom, 2011), one would expect that the additional load carriage might increase differences between the sides of the body for up to 50% (Zang et al., 2010). For lower extremities, studies have predominately wanted to examine whether the asymmetrical load carriage tends to have an effect on biomechanical gait parameters (Seelay et al., 2008; Shi et al., 2015; Park et al., 2015; Zang et al., 2010; DeVita et al., 1991; Majumdar et al., 2013). In general, an uneven load increases hip and knee extensor moments of the unloaded leg (DeVita et al., 1991), changing knee biomechanics (Park et al., 2015; Ozgül et al., 2012). However, little evidence has been provided regarding carrying load and gait asymmetry (Zang et al., 2010). For example, a study by Zhang et al. (2010) has shown that asymmetry in ground reaction forces in medio-lateral direction is significantly greater under 20% body weight conditions, compared to 0 to 10% conditions. Indeed, the asymmetrical changes under different load conditions come from inertial characteristics of locomotor system and the restriction of natural arm swing patterns (Umberger, 2008).

To the best of authors’ knowledge, there has been lacking studies examining the effects of carrying load on spatiotemporal gait characteristics. Since carrying police equipment may cause larger foot rotation, decreases in step and stride length and increases in step and stride time (Kasović et al., 2020), it is reasonable to hypothesize that such load can produce even larger gait asymmetries. From a practical point of view, load carriage may increase the incidence of musculoskeletal injury rate (Teyhen et al., 2020; Yavnai et al., 2021) and stress syndrome (Sharma et al., 2014), which may limit duty time and increase the odds for hospitalization Chavet et al., 1997). Also, it would be possible for policy makers to redesign the existing police load and redistribute necessary load parts to decrease gait asymmetry.

Given the importance of symmetrical gait during completition of everyday tasks and assignments, one would expect that additional load might produce changes in spatial and temporal gait parameters and directly impact on gait asymmetries. Such uneven values on the left and right sides of the body could possibly lead to changes in body posture and a decrease in performance, and even to a higher risk of injuries. On the other hand, examining how body asymmetry changes under a certain loading condition could give a meaningful insight of re-structuring/organizing the existing load, so it produces less hazardous biomechanical effects on the body during walking. Finally, public health policy makers may expand their knowledge of safety issues of the load, and how the findings may be implemented to other occupations, which are at higher risk of excessive load carriage.

Therefore, the main purpose of the present study was to examine whether standardized equipment produced greater spatiotemporal gait asymmetries in a large sample of police recruits. Since external load of police officers is not unique for both sides of the body, we hypothesized, that an external load being carried by police officers might produce greater spatial and temporal gait asymmetries, especially during different gait cycles and unilateral/bilateral support between the body and the ground.

9.4. Materials and methods

Study participants

In this cross-sectional study, we recruited police recruits, who were part of the one-year academy training program aiming to become a part of Croatian police service. A training program consists of monitoring and improving health-related physical fitness and learning everyday specific tasks and duties on the field. Technical and tactical parts of the program include handling a gun and behaving in high-risk situations, which is often accompanied by psychological preparation and the assessment of environment. All these tasks are completed while carrying out standardized police equipment on a daily basis. In general, a police academy recruits between 750 and 1,000 every year. In 2022, when the study had been conducted, 900 police recruits were examined and selected to participate in the study. The inclusion criteria strictly stated that all participants needed to be without locomotor and mental acute or chronic diseases, which could prevent them from taking part in the study. Also, each participant had to be in the training program of the police academy and should attend planned programs, tasks and assignments on a regular basis. The exclusion criteria included participants suffering from locomotor (injury) or mental (depression or any other disease) and those who were ill at the time the study had been conducted. All participants had been given information regarding general and specific aims, hypotheses, benefits and potential risks. All the procedures were anonymous and in accordance with the Declaration of Helsinki. Furthermore, all participants gave written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

Load equipment

For the purpose of this study, we selected standard police equipment carried during police training, which consisted of a belt (≈0.5 kg; 1.1 lb), a gun with a full handgun's magazine (≈1.5 kg; 3.3 lb), an additional full handgun's magazine (≈0.5 kg; 1.1 lb), a nightstick (≈0.8 kg; 1.8 lb) and handcuffs (≈0.2 kg; 0.5 lb). In total, the whole equipment without a police suit weigh ≈3.5 kg (7.7 lb). Of note, the participants wore the 3.5 kg load on a daily basis, but only when specific tasks and assignments were conducted with a duration of approximately 4 hours/day. The intention of wearing the load on a daily basis was because the participants got familiar with the design and the feeling of carrying an external load on one side, and how they would complete the police program and given tasks and assignments in specific, real-life situations when carrying it on the other side.

Spatiotemporal gait analysis

In order to calculate spatiotemporal gait parameters, we tested all the study participants with the Zebris pedobarographic platform (FDM; GmbH, Munich, Germany; number of sensors: 11.264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm), a multisensory device aimed to record, process and generate gait characteristics in dynamic (walking) and static (quiet standing) conditions. The platform was positioned on the ground with additional custom-made wooden platforms (each 4.5 m in length) placed before and after the Zebris platform to make the walking surface even. The testing procedure included each participant to walk normally at a comfortable speed and without shoes over the first wooden platform to gain an adequate acceleration and gait pattern, reaching to the pressure platform to collect the data and finishing on the second wooden platform to decelerate, after which the participant stopped at the end of a walkway, turned around for 180° and continued to walk over the platforms to the starting point. The condition of walking without shoes was used, because the design of shoes worn by police recruits is specific, due to the fact that the sole of the shoe is about 2 to 3 centimeters thick, and based on this, it can absorb a certain number of forces and pressures under certain regions of the foot, which directly affects the spatial and temporal parameters of gait. Also, the same methodology has been used previously in a similar sample (Kasović et al., 2020). This task was completed eight times (van der Leeden et al., 2004). After completing the first task, the same task was repeated while carrying police equipment. The software generated the data regarding foot rotation (°, measured as the position of both feet on the ground while walking and being compared to the platform, where the angle between each foot placement and the platform served as the foot rotation), step length (cm), stride length (cm), step width (cm), gait cycle phases (%, stance, load response, single limb support, pre-swing, swing and double support), step time (s), stride time (s), cadence (steps/min) and walking speed (km/h).

Statistical analysis

The Kolmogorov-Smirnov test was used to assess the normality of the study variables. Basic descriptive statistics of the study participants are presented as mean and standard deviation (SD) for normally distributed variables and median and interquartile range (25^{th} and 75^{th} percentile) for not normally distributed variables. Accordingly, differences in gait characteristics between 'no load' vs. 'a 3.5 kg/7.7 lb load' were examined using Student t-test for dependent sample (one sample in two load conditions) or Wilcoxon signed-rank test. Since each participant completed the task eight times for a given parameter, we calculated the differences between each trial using the repeated measures analysis of variance and investigated internal reliability using cross-correlation analysis with Cronbach's alpha and the coefficient of variation. The reason for such approach was using the mean and SD of all eight trials for a single spatial and temporal gait parameter. The same methodology has been previously described (van der Leeden et al., 2004) and used (Kasović et al., 2020) in similar populations. No significant differences between the trials in spatial and temporal gait parameters were observed (p = 0.583 – 0.873), Cronbach's alpha showed excellent internal reliability (0.87 – 0.96) with a coefficient of variation of 1.1%, indicating that mean with SD were appropriate descriptive statistics for further analyses. Gait asymmetries were calculated using the formula proposed by Robinson et al.[21]: $(x_{right} - x_{left})/0.5*(x_{right} + x_{left}) *100\%$, where 'x' represented a given parameter being calculated. A score of 0 denotes perfectly symmetric gait, while as the value increases in both positive and negative direction, asymmetry increases. The statistical significance was set at a priori $p \leq 0.05$. For the purpose of examining the effects of 'a 3.5-kg/7.7

lb load' vs. no load' on spatial and temporal gait parameters, we additionally calculated Cohen's *D* effect sizes (ES) and interpreted them as small (0.2), medium

Table 1. Basic descriptive statistics of the study participants

Variables	Mean (SD)/N (%)	Min - Max	Range
Sex			
Men	609 (72.1%)		
Women	236 (27.9%)		
Age (years)	21.3 ± 2.1	18.7 – 24.7	6.0
Height (cm)	175.2 ± 14.3	164.3 – 190.8	26.5
Weight (kg)	74.4 ± 14.5	57.3 – 100.6	43.3
Body mass index (kg/m^2)	24.3 ± 4.8	19.4 – 28.3	8.9
Nutritional status (%)			
Normal weight (< 25kg/m^2)	710 (84.0%)		
Overweight (< 30 kg/m^2)	93 (11.0%)		
Obesity (≥ 30 kg/m^2)	42 (5.0%)		
Socioeconomic status (%)			
Below average	245 (29.0%)		
Average	450 (53.3%)		
Above average	150 (17.7%)		

(0.5) and large (0.8).[22] All analyses were performed in Statistical Packages for Social Sciences (SPSS Inc., Chicago, Illinois, USA).

9.5. Results

At the beginning, 900 participants were eligible to be part of the study. Based on inclusion and exclusion criteria, 55 were excluded, due to illness or musculoskeletal injury obtained during the training process. Thus, our final sample included in further analyses was based on 845 (93.4% of the initial sample) police recruits ((mean ± SD); age: 21.2 ± 2.3 years; height: 178.1 ± 10.2 cm; weight: 78.4 ± 11.3 kg; body mass index: 24.7 ± 3.2 kg/m^2; 609 men and 236 women; 72.1% men and 27.9% women)). Basic descriptive statistics of the study participants are presented in Table 1. Roughly 2/3 of the study participants were men (N = 609; 72.1%), opposed to 27.9% women (N = 236). All the study participants were categorized as young adults between ages 18 and 25 years of age, with a 'normal' body mass index. Most of the participants rated their socioeconomic status as 'average'.

Changes in spatial and temporal gait parameters are presented in Table 2. In general, no significant differences in spatiotemporal gait parameters between 'no load' vs. a 3.5-kg/7.7 lb load' were observed. However, significant differences in load response phase for the right foot, pre-swing phase for the left foot, swing phase for the right foot and step time for the right foot. Of note, to determine whether sex had a significant impact on changes in spatial and temporal gait parameters, a time*sex interaction for each of the study variable was calculated. In further analyses, we found no significant time*sex interaction in asymmetries of spatial gait parameters for foot rotation ($F_{1,833}$ = 0.555, p = 0.320), step length ($F_{1,833}$ = 0.125, p = 0.723), stance ($F_{1,833}$ = 1.047, p = 0.187), load response ($F_{1,833}$ = 0.944, p = 0.235), single limb support ($F_{1,833}$ = 1.047, p = 0.187), pre-swing ($F_{1,833}$ = 0.745, p = 0.411), swing ($F_{1,833}$ = 0.226, p = 0.187) and double stance phase ($F_{1,833}$ = 1.233, p = 0.99) of the gait. For temporal gait parameters, no significant time*sex

Table 2. Gait spatiotemporal descriptive statistics of the study participants

Study variables	**'No load'**	**'a 3.5-kg/7.7 lb load'**	***P* - value**
	Mean (SD)	Mean (SD)	
Foot rotation (°)			
Left foot	6.16 (6.50)	5.61 (6.98)	0.131
Right foot	8.60 (6.88)	8.23 (6.27)	0.291
Step length (cm)			
Left foot	64.94 (6.28)	65.04 (6.27)	0.754
Right foot	64.61 (6.16)	64.59 (5.98)	0.930
Step width (cm)	12.80 (3.06)	12.65 (3.01)	0.301
Gait cycle components:			
Stance (%)			
Left foot	62.28 (3.19)	62.37 (2.49)	0.538
Right foot	62.31 (2.52)	62.51 (2.43)	0.125
Load response (%)			
Left foot	12.42 (2.85)	12.40 (1.97)	0.858
Right foot	12.40 (2.04)	12.64 (1.98)	0.026
Single limb support (%)			
Left foot	37.55 (2.88)	37.34 (2.75)	0.156
Right foot	37.51 (2.30)	37.49 (2.28)	0.894
Pre-swing (%)			
Left foot	12.46 (1.92)	12.75 (2.50)	0.017
Right foot	12.40 (1.88)	12.46 (1.86)	0.578
Swing (%)			
Left foot	37.62 (2.58)	37.55 (2.14)	0.590
Right foot	37.71 (2.55)	37.45 (2.13)	0.024
Double stance phase (%)	25.08 (7.77)	25.11 (3.25)	
Step time (s)			
Left foot	0.56 (0.04)	0.56 (0.04)	0.708

Right foot	0.56 (0.04)	0.56 (0.04)	0.050
Stride time (s)	1.31 (0.15)	1.32 (0.15)	0.966
Cadence (steps/min)	108.09 (19.23)	108.37 (14.0)	0.857
Walking speed (km/h)	4.25 (2.05)	4.64 (1.56)	0.371

interaction for asymmetries for step time ($F_{1,833}$ = 1.445, p = 0.065), stride time ($F_{1,833}$ = 1.399, p = 0.071), cadence ($F_{1,833}$ = 0.887, p = 0.722) and gait speed ($F_{1,833}$ = 0.744, p = 0.756) were found. Therefore, the results were presented as combined values of men and women, respectively.

Table 3 shows symmetry indexes for spatiotemporal gait parameters. When carrying 'a 3.5-kg/7.7 lb load', participants significantly increased their asymmetries in gait cycle phases, especially in stance (ES = 0.14), load response (ES = 0.13), single limb support (ES = 0.10), pre-swing (ES = 0.24) and swing (ES = 0.20) gait cycles and step time (ES = 0.15), while no significant asymmetry changes with trivial effects in other parameters were observed (p > 0.05). Also, no significant changes occurred in step width, double stance phase, stride time, cadence and walking speed.

9.6. Discussion

The main purpose of the present study was to examine whether standardized equipment produced greater spatiotemporal gait asymmetries in a large sample of police recruits. The main findings of the study are: i) a 3.5-kg/7.7 lb load' significantly increases asymmetries in gait cycle, especially for stance, load response, single limb support, pre-swing and swing phases; and ii) asymmetry index in step time also increases, following 'a 3.5- kg/7.7 lb load', compared to 'no load' condition. Based on the aforementioned findings, the hypothesis of an increased spatial gait asymmetry when carrying 'a 3.5 kg/7.7 lb' load can be accepted, especially when the results are observed in terms of different gait cycles. For temporal gait parameters, only the asymmetry in step time is observed, meaning that the second hypothesis can be partially accepted.

To the best of authors' knowledge, this is the first study examining asymmetry differences during different load conditions in police recruits. Indeed, a common method to define gait asymmetry between the left and right feet has been by measuring ground reaction forces, often in stance position (Chavet et al., 1997; Maines & Reiser, 2006). The findings of these studies have suggested that between 65 and 75% of respondents are asymmetrical, especially in vertical and medial/lateral direction (Maines & Reiser, 2006). However, an asymmetrical analysis during gait has been less studied (Zhang et al., 2010). In a study by Zhang et al (2010) the asymmetry in ground reaction forces increased after additional load, indicating that such load might cause different effects in the left and right foot. Although the aforementioned study did not assess spatiotemporal gait parameters, increased asymmetry in gait cycle phases obtained in this study could be explained by cumulative effects of changing the inertial patterns of musculoskeletal system and the restriction of natural arm swing, due to load characteristics and lateral trunk position (Umberger, 2008; Birrell e al., 2007). For example, previous evidence suggests that the trunk often deviates away from the loaded side, pointing out that motor control actions following external load might be associated with strategies of load carriage and load characteristics, including weight and shape (Zhang et al., 2010). Postural adaptations between the left and right side of the body are due to a preferred handedness and changes in neuromuscular system. Although the mechanism underlying gait asymmetries is because of stride length, cadence and walking speed (Boffey et al., 2019), we observed no significant changes in these parameters following 'a 3.5-kg/7.7 lb load', expanding the understanding of asymmetry increases to other factors, including load patterns and physiological adaptations (Boffey et al., 2019). In this study, a 3.5-kg/7.7 lb load' had small, but significant effects on gait asymmetry, but these changes were likely to be explained by load placement (Stuempfle et al., 2004) and higher energy expenditure (Quesada et al., 2000).

Table 3. Symmetry indexes for spatiotemporal gait parameters based on the left and right side of the body

Study variables	‘No load’	‘a 3.5-kg load’	Mean diff.	95% mean diff.	*P* - value
	Mean (SD)	Mean (SD)			
Foot rotation (°)	0.82 (4.23)	0.54 (3.16)	0.29	-0.11 to 0.68	0.153
Step length (cm)	-0.82 (12.85)	-1.21 (13.05)	0.39	-0.98 to 1.76	0.580
Stance (%)	-0.01 (8.14)	1.04 (6.68)	-1.05	-1.83 to -0.26	0.009
Load response (%)	-0.09 (3.26)	0.21 (1.03)	-0.31	-0.56 to -0.05	0.020
Single limb support (%)	-0.12 (4.85)	0.44 (4.62)	-0.57	-1.06 to -0.06	0.030
Pre-swing (%)	-0.03 (0.90)	-0.25 (1.60)	0.22	0.08 to 0.37	0.002
Swing (%)	-0.16 (5.02)	0.74 (4.03)	-0.90	-1.38 to -0.42	< 0.001
Step time (s)	0.00 (0.00)	-0.01 (0.00)	-0.01	-0.01 to -0.02	0.020

The most appropriate way of carrying a load is via backpack, keeping the load near the center of gravity (Heglund et al., 2000). In police recruits, load characteristics include placing a handgun to the dominant side of the body. Even though the effectiveness of such position has merit, by sticking out, the subject often tends to compensate body posture by limited arm swing on the side the handgun is placed and lowering the opposite shoulder for better frontal propulsion (Boffey et al., 2019). From a physiological point of view, Quesada et al. (2000) showed that an increase in load carriage by 15% body weight increased metabolic cost by 5-6%. While a relative value of ‘a 3.5-kg/7.7 lb load’ was around 5% for our sample, which might not be enough to produce higher metabolic cost, a low load has been shown to cause a more drastic forward lean which can further distort gait patterns.[28]

Although a load carriage of 3.5 kg/7.7 lb may not seem to be high enough to produce negative gate changes, the findings of this study showed that it might increase asymmetries during gait cycle, causing additional body disproportion and embracing poor gait adjustments. Loss of stability during gait while carrying load primarily affects antero-posterior and medio-lateral planes of the foot,[5] increasing ground reaction forces and plantar pressures and leading to possible discomfort and pain during walking. In that way, the discrepancy between the left and right foot may increase, potentially leading to greater asymmetries in gait parameters (Goffar et al., 2013; Majumdar et al., 2010; Park et al., 2013).

This study is not without limitations. Due to a cross-sectional design, we cannot determine causal changes in asymmetry, limiting the generalizability of the findings to police recruits, who were still not experienced in police tasks and equipment. Second, we only examined spatiotemporal gait parameters, while 3-D kinematic and electromyography systems would have given more information regarding increased gait asymmetries following 'a 3.5-kg/7.7 lb load'. Third, we did not collect biological and physiological parameters, which may interrogate between dynamic foot parameters and load carriage. 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 load items and exploring potential effects of load carriage on the incidence of injuries. Finally, participants walked barefoot over the pressure platform, which might have affected gait patterns. Thus, future research aiming to examine gait asymmetries during load carriage should focus on follow-up design and complete physiological and biomechanical analyses, load- and injury-related characteristics, which may be important communicable factors for limiting negative effects of load carriage on the gait.

9.7. Conclusions

In summary, this study shows that ‘a 3.5-kg/7.7 lb load’ may increase gait cycle asymmetries during stance, load response, single limb support, pre-swing and swing phases, while temporal parameter of step time asymmetry is also increased. These findings imply that a standardized load worn by police recruits during preparation training may have a negative impact on gait characteristics, especially in terms of gait cycle and step time, which suggest that such equipment should be ergonomically re-designed to minimize the impact on spatiotemporal gait parameters. Although our findings showed small but significant effects of carrying a load of ‘a 3.5 kg/7.7 lb’ on gait parameters, especially in gait cycles and step time, the practical value of the research could contribute to the re-organization of individual components of police equipment, with the aim of the appearance of smaller asymmetries and the maintenance of similar biomechanical performance between the left and right side of the body. Also, by lowering the position of a handgun on the thigh surface, individuals would be able to move the arm swiftly, leaning the trunk from the opposite to the more neutral position of the body center and evenly re-distribute the applied force on the ground.

9.8. RESEARCH STUDY TWO

Article title

Carrying Police Load Increases Gait Asymmetry in Ground Reaction Forces and Plantar Pressures Beneath Different Foot Regions in a Large Sample of Police Recruits

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9.9. ABSTRACT

Background

Although carrying external load has negative effects on gait biomechanics, little evidence has been provided regarding its impact on body asymmetry. The main purpose of the present study was to examine whether standardized equipment produced greater gait asymmetries in ground reaction force and plantar pressure.

Methods

For the purpose of this study, we recruited 845 police recruits (609 men and 236 women; 72.1% men and 27.9% women) measured in two conditions: i) 'no load' and ii) 'a 3.5 kg load'. Absolute values in ground reaction forces and plantar pressures beneath the different foot regions were assessed with pedobarographic platform (Zebris FDM). Asymmetry was calculated as $(x_{right} – x_{left})/0.5*(x_{right} + x_{left})$ *100%, where 'x' represented a given parameter being calculated and a value closer to 0 denoted greater symmetry.

Results

Significant differences in ground reaction forces and plantar pressures between the left and right foot were observed, when adding "a 3.5-kg load". Compared to 'no load' condition, carrying 'a 3.5-kg load' significantly increased gait asymmetries for maximal ground reaction forces beneath the forefoot (ES = 0.29), midfoot (ES = 0.20) and hindfoot (ES = 0.19) regions of the foot. For maximal plantar pressures, only the asymmetry beneath the midfoot region of the foot significantly increased (ES = 0.19).

Conclusion

Findings of this study indicate that 'a 3.5-kg load' significantly increases ground reaction force and plantar pressure gait asymmetries beneath the forefoot and midfoot regions, compared to 'no load' condition. Due to higher loads, increases in kinetic gait asymmetries may have negative effects on future pain and discomfort in the foot area, possibly causing stress-fractures and deviated gait biomechanics in police recruits.

Key words: special populations, police equipment, load carriage, symmetry, effect size

10. Introduction

Load carriage in special populations, like police officers, is considered a crucial component of everyday physical activity and successful performance of occupational tasks (Larsen et al., 2016; Joseph et al., 2018). Although such load may have beneficial effects for on-duty protection and completing the tasks at maximal level (Boffey et al., 2019; Walsh & Low, 2021), previous research has highlighted negative effects of the load on one's health and well-being (Salvendy, 2012), primarily focusing on physiological (Boffey et al., 2019; Faghy et al., 2022) and biomechanical changes (Boffey et al., 2019; Walsh & Low, 2021). In the field of physiology, carrying an external load and gait propulsion may produce higher energy expenditure (Boffey et al., 2019). On the other hand, from a biomechanical point of view, added mass to body weight may increase moments in the trunk, hip and knee flexion and extension areas, while inconclusive data between the load carriage and ground reaction forces and plantar presures are detected (Walsh & Low, 2021). Both physiological and biomechanical consequences of carrying heavy loads can also increase the fatigue (Fallowfield et al., 2012) and the incidence of musculoskeletal injuries (Orr et al., 2015; Orr et al., 2021).

Studying gait symmetry has often been a topic of interest for health-care professionals to detect gait characteristics in normal population (Handžić & Reed, 2015), and identifying injury risk (Helme et al., 2021). A 'perfect symmetry', indicating an equal degree for a given parameter between the left and right foot, has been set to be between 5-15% for some motor abilities, like strength (Lanshammar & Ribom, 2011). It is reasonable to expect that carrying loads may naturally affect gait asymmetry for up to 50% (Zhang et al., 2010). With that in line, available studies have shown, that carrying an extra load potentially increases hip and knee extensor moments of the unloaded leg (DeVita et al., 1991), changing knee biomechanics (Ozgül et al., 2012; Park et al., 2018). Although a common method for assessing the degree of symmetry has been by measuring ground reaction forces (Davids et al., 2006), the majority of previous studies have investigated the effects of external load on ground reaction force and plantar pressure gait asymmetries during quiet stance (Meines & Reiser, 2006; Rocheford et al., 2006), with limited information for such phenomenon during gait (Zhang et al., 2010). A study by Zhang et al. (2010) has concluded that carrying load of 20% body mass increases ground reaction force asymmetries in medio-lateral planes, compared to 0 to 10% conditions. Indeed, an increased gait asymmetry and body compensation following load carriage come from inertial characteristics of musculoskeletal system (Umberger, 2008).

To the best of authors' knowledge, there has been lacking studies examining the effects of load carriage on gait asymmetries in terms of ground reaction forces and plantar pressures. Since 'a perfect symmetry' between the sides of the body without carrying a load does not exist, we can speculate that an additional mass added on the body may even increase gait asymmetry in the aforementioned gait parameters. Indeed, higher level of ground reaction forces and plantar pressures have been constantly associated with higher incidence of musculoskeletal injury rate (Teyhen et al., 2020; Yavnai et al., 2021), which can increase and prolong hospitalization time (Canham-Chervak et al., 2018). Although a load carriage is a necessity for special populations, re-distributing load items on the body may be a crucial part for minimizing negative impacts on gait biomechanics.

Therefore, the main purpose of the present study was to examine whether standardized equipment produced greater ground reaction force and plantar pressure gait asymmetries in a large sample of police recruits. We speculated that such a load might increase ground reaction force and plantar pressure asymmetries, especially beneath the hindfoot and forefoot regions.

10.1. Materials and methods

Study participants

For the purpose of this study, we recruited 900 police recruits, who were part of Croatian police service at the time. More detailed information about recruitment, sample size characteristics, inclusion and exclusion criteria and data regulations can be found elsewhere (Štefan et al., 2024a). In brief, every year, a police academy recruits and welcomes around 900 healthy men and women, who undertake special police training program in the duration of one year. In 2023, we were able to recruit all 900 first-year police recruits and 845 of them had eligible data for further analyses (27.9% women). Before the study had been conducted, all participants became familiar with aims, hypotheses, benefits and potential risks of the study and how the findings might translate into practice. Following the Declaration of Helsinki procedure, all analyses were anonymous, and all participants gave written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

Load equipment

A standardized load equipment being carried by police recruits involved a belt with a gun and a full handgun's magazine, an additional full handgun's magazine, a nightstick and handcuffs, where the final weigh was around 3.5 kg (7.7 Ibs) (Štefan et al., 2024a; Štefan et al., 2024b).

Ground reaction forces and plantar pressures

Ground reaction forces and plantar pressures beneath different foot regions were analyzed by objective method of the Zebris pedobarographic platform (FDM; GmbH, Munich, Germany; number of sensors: 11.264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm). The device uses a multisensory principle which may capture spatiotemporal and kinetic gait characteristics during walking or standing positions. More detailed information of testing protocols and generating the data can be found elsewhere (Štefan et al., 2024a; Štefan et al., 2024b). In brief, each participant walked at a preferred gait speed over the platform eight times (van der Leeden et al., 2004), being instructed not to target the platform or changing the patterns of the walk. After completing the first task, the same task was repeated while carrying police equipment. The kinetic gait parameters included generating data regarding maximal ground reaction forces (N) and plantar pressures (N/cm^2) of the left and right foot of the body for the forefoot, midfoot and hindfoot regions.

Data analysis

All procedures were analyzed using Statistical Packages for Social Sciences software (SPSS Inc., Chicago, Illinois, USA). First, to test the normality of the study variables, we used Kolmogorov-Smirnov test. For normally and not normally distributed variables, descriptive statistics are presented as mean and standard deviation (SD) or median and interquartile range (25^{th} and 75^{th} percentile). Student t-test for dependent samples or Wilcoxon singed-rank test were used to examine differences between 'no load' vs. 'a 3.5 kg load'. To examine gait asymmetries, we used the formula proposed by Robinson et al. (1987): $(x_{right} – x_{left})/0.5*(x_{right} + x_{left})$ *100%, where an 'x' represented a given parameter. A final score closer to 0 denotes more symmetrical gait, while a score that deviates more from 0 denotes greater asymmetry. Effect size (ES) was used to express the magnitude of the difference between groups and was presented as 'small' (0.2), 'moderate' (0.5), 'large' (0.8) (Sullivan & Feinn, 2012). The significance was set at a priori $p \leq 0.05$.

10.2. Results

Socio-demographic characteristics of the study participants are presented in Table 1. The data of table 1 relied on one previous study published by the same authors (Štefan et al., 2024).

Table 1. Basic descriptive statistics of the study participants

Variables	**Mean (SD)/N (%)**	**Min - Max**	**Range**
Sex			
Men	**609 (72.1%)**		
Women	**236 (27.9%)**		
Age (years)	**21.3 ± 2.1**	**18.7 – 24.7**	**6.0**
Height (cm)	**175.2 ± 14.3**	**164.3 – 190.8**	**26.5**
Weight (kg)	**74.4 ± 14.5**	**57.3 – 100.6**	**43.3**
Body mass index (kg/m^2)	**24.3 ± 4.8**	**19.4 – 28.3**	**8.9**
Nutritional status (%)			
Normal weight (<25kg/m^2)	**710 (84.0%)**		

Overweight (< 30 kg/m^2)	**93 (11.0%)**		
Obesity (≥ 30 kg/m^2)	**42 (5.0%)**		
Socioeconomic status (%)			
Below average	**245 (29.0%)**		
Average	**450 (53.3%)**		
Above average	**150 (17.7%)**		

Changes in ground reaction forces and plantar pressures are presented in Table 2. When carrying ‘a 3.5-kg load’, significant differences in ground reaction forces for left forefoot (Δ = 2.9%), left midfoot (Δ = 3.6%), right midfoot (Δ = 3.6%) and right hindfoot (Δ = 1.7%) were observed. For plantar pressures, a load of 3.5-kg significantly increased the area beneath left forefoot (Δ = 2.0%), right forefoot (Δ= 1.2%) and right midfoot (Δ= 0.4%). Finally, the % of time maximal force during stance time was significantly increased beneath left forefoot (Δ = 0.5%) and right midfoot (Δ = 0.8%), while a significant decrease in left midfoot was shown. Changes in gait asymmetries according to sex showed no significant time*sex interactions for ground reaction forces beneath the forefoot ($F_{1,833}$ = 0.616, p = 0.433), midfoot ($F_{1,833}$ = 0.347, p = 0.556), and hindfoot ($F_{1,833}$ = 0.750, p = 0.387) regions of the foot. Also, when force was applied to a surface as a plantar pressure, we observed no significant time*sex interaction for asymmetries beneath the forefoot ($F_{1,833}$ = 0.743, p = 0.392), midfoot ($F_{1,833}$ = 0.422, p = 0.588) and hindfoot ($F_{1,833}$ = 0.255, p = 0.650) regions of the foot.

Table 2. Gait changes (mean ± SD) in ground reaction forces and plantar pressures beneath different foot regions.

Study variables	**Load condition**			
Maximal ground reaction forces	**'No load'**	**'a 3.5-kg load'**	***t* - value**	***P* - value**
Left foot				
Forefoot (N)	758.58 (130.70)	780.44 (135.94)	-3.351	< 0.001
Midfoot (N)	145.58 (71.58)	150.83 (78.34)	-2.083	0.037
Hindfoot (N)	513.65 (98.57)	524.38 (98.53)	-1.432	0.152
Right foot				
Forefoot (N)	766.11 (304.00)	798.78 (336.76)	-1.497	0.135
Midfoot (N)	156.84 (79.10)	162.52 (76.32)	-2.227	0.026
Hindfoot (N)	500.23 (98.86)	508.53 (98.31)	-1.923	0.045
Maximal plantar pressures				
Left foot				
Forefoot (N/cm^2)	44.40 (9.80)	45.28 (9.76)	-1.857	0.049
Midfoot (N/cm^2)	15.01 (7.54)	15.31 (7.60)	-1.088	0.277
Hindfoot (N/cm^2)	33.05 (7.59)	33.69 (7.28)	-0.809	0.419
Right foot				
Forefoot (N/cm^2)	44.55 (10.07)	45.08 (9.91)	-1.900	0.046
Midfoot (N/cm^2)	15.03 (6.52)	15.64 (6.62)	-1.855	0.049
Hindfoot (N/cm^2)	31.89 (7.07)	32.46 (7.16)	-1.646	0.100
Time maximal force, % of stance time				
Left foot				
Forefoot (%)	74.44 (2.44)	74.79 (2.13)	-3.101	0.002
Midfoot (%)	41.30 (9.62)	41.02 (9.82)	-2.538	0.011

Hindfoot (%)	18.47 (3.69)	18.88 (3.60)	0.570	0.569
Right foot				
Forefoot (%)	74.16 (3.48)	74.52 (2.28)	-0.596	0.552
Midfoot (%)	39.70 (9.02)	40.00 (9.10)	-2.303	0.021
Hindfoot (%)	18.06 (3.74)	18.27 (4.05)	-1.102	0.271

Table 3 shows asymmetry characteristics in 'no load' and 'a 3.5-kg load' conditions between the left and right foot. Most notably, a 3.5-kg load' significantly increased asymmetries in forefoot (ES = 0.29), midfoot (ES = 0.20) and hindfoot (ES = 0.19) regions of the foot for ground reaction forces. For plantar pressures, only the asymmetry beneath the midfoot region of the foot significantly increased (ES = 0.19). Also, the % of time maximal force during stance time significantly increased beneath the hindfoot (ES = 0.17) region of the foot, while other asymmetries were non-significant.

Table 3. Differences in asymmetries between the left and right foot of the body in 'no load' vs. 'a 3.5-kg load' (mean ± SD)

Study variables	**Asymmetry**		**Mean diff.**	**95% mean diff.**	***P* - value**
Ground reaction forces	**'No load'**	**'a 3.5-kg load'**			
Forefoot	0.000 (0.049)	0.014 (0.010)	-0.014	-0.021 - 0.006	< 0.001
Midfoot	0.038 (0.192)	0.076 (0.201)	-0.038	-0.056 - 0.019	< 0.001
Hindfoot	-0.014 (0.058)	-0.025 (0.058)	0.011	0.005 - 0.017	< 0.001
Plantar pressures					
Forefoot	0.001 (0.092)	0.000 (0.089)	0.001	-0.008 - 0.010	0.797
Midfoot	0.009 (0.171)	0.041 (0.172)	-0.032	-0.049 - 0.016	< 0.001
Hindfoot	-0.017 (0.085)	-0.019 (0.071)	0.002	-0.005 - 0.010	0.571
Time maximal force, % of stance time					

Forefoot	-0.003 (0.036)	-0.002 (0.017)	-0.001	-0.003 - 0.002	0.640
Midfoot	-0.018 (0.105)	-0.011 (0.104)	-0.007	-0.017 - 0.003	0.161
Hindfoot	-0.013 (0.102)	-0.030 (0.101)	0.018	0.008 - 0.027	< 0.001

10.3. Discussion

This study aimed to investigate the effects of carrying load on ground reaction force and plantar pressure gait asymmetries. The main findings of the study are: i) a 3.5-kg load' significantly increases asymmetries in ground reaction forces, especially in the forefoot and midfoot regions; and ii) asymmetry index in plantar pressure also increases, with the largest magnitudes being observed for the forefoot region.

Based on the findings available, this research represents one of the initial examinations of differences in asymmetry under various load conditions among police recruits. As discussed in the 'Introduction' section, previous approaches to defining gait asymmetry between the left and right foot have typically involved measuring ground reaction forces during stance (Chavet et al., 1997; Maines & Reiner, 2006). However, there has been limited study on asymmetrical gait analysis during actual gait (Zhang et al., 2010). Notably, when carrying heavy loads, gait asymmetry in ground reaction forces becomes more pronounced, resulting in differing impacts on the left and right foot. Previous studies have employed asymmetric/unilateral loads to assess the effects of such equipment on kinematic and kinetic gait parameters (DeVita et al., 1991; Zhang et al., 2010; Ozgül et al., 2012; Park et al., 2018; Alamoudi et al., 2018). In cases of asymmetric lifting, greater loads are placed on the musculoskeletal system, particularly the trunk, when compared to symmetric lifting techniques (DeVita et al., 1991). Additionally, the increased asymmetry in ground reaction forces and plantar pressures observed in this study could be attributed to cumulative effects resulting from changes in the inertial patterns of the musculoskeletal system and the restriction of natural arm swing due to load characteristics and lateral trunk position (Birrell et al., 2007; Umberger et al., 2008). These findings align with previous research suggesting that deviations in trunk movement away from the loaded side are indicative of motor control actions related to load carriage strategies and characteristics such as weight and shape (Zhang et al., 2010). Furthermore, it has been observed that compensations between the sides of the body are associated with preferred handedness and alterations in the neuromuscular system.In a study by Alamoudi et al. (2018), 20 males carried a load of 10 lbs (≈ 4.5 kg) in four different modalities of frontal, lateral, bilateral and posterior positions while walking over a Kisler platform. Similar to our findings, the compression and shear forces significantly increased with the magnitude of the weight carried, especially in lateral position. This is not surprising, since in our study, a gun with a full handgun magazine was positioned sideways (left or right side of the body) and might have led to even greater asymmetries. Because of the nature of the load carried, participants counterbalance the weight by flexing the trunk, which may lead to an increased distance between the center of mass of the body and weight (Holbein & Redfern, 1994). Although the latero-flexion of the trunk in opposite direction prevents it from falling and restore body balance, it reduces gait stability (Fowler et al., 2006) and increases gait asymmetry (Zhang et al., 2010). Also, greater gait asymmetries are often explained by the increased cadence, which reduces the stress on the joints of the lower limb (Singh & Koch, 2009). Through an exploration of various factors such as load patterns and physiological adaptations (Boffey et al., 2019), policymakers in the healthcare field could potentially revamp existing load structures and adjust their placement on the body. According to a study, the introduction of a '3.5-kg load' was found to have a minor yet noteworthy impact on kinetic gait asymmetry. These alterations were believed to be linked to load placement (Stuempfle et al., 2004) and increased energy consumption (Quesada et al., 2000). This has been supported previously, where larger individuals classified as 'obese' increase their oxygen and carbon oxide consumption, relative energy expenditure and heart rate (Lemus et al., 2022). Indeed, obese individuals tend to have higher cardiac stroke volume and a higher mechanical demand on the lungs, which increases inspiratory and expiratory gas volumes and leads to breathing inefficiency (Lemus et al., 2022). To overcome this problem, we tested the interaction effect of body mass index on gait asymmetries and found non-significant main effects for both men and women, respectively. The cumulative effects of body mass index and 'a 3.5-kg load' carried may not be sufficient to exhibit significant gait changes. First, the participants recruited for this study were somewhat homogenous groups of healthy individuals, with many of them being classified as 'normal weight'. Second, heavier load carried linearly leads to greater gait changes (Alamoudi et al., 2018) and asymmetries in ground reaction forces and plantar pressures (Zhang et al., 2010), while 'a 3.5-kg load' does not seem to produce such large, but only small effects. Based on the evidence, it is suggested that the safest and most biomechanically appropriate way to carry a load is by using a backpack, keeping the load close to the center of gravity (Heglund et al., 1995). Although we observed only trivial to small differences between ‘no load’ vs. a 3.5-kg load’, there is still an implication of our findings in terms of re-positioning the items of the load. For example, the handgun can be moved to the lateral side of the thigh area to prevent the arms from moving swiftly while walking. We descriptively observed that the dominant arm often ‘freezes’ during gait, which increases movements on the opposite side of the body by increasing the lateral flexion of the trunk. In Croatia, the internal policy still dictates that police loads need to be attached around the hips, and future research on this topic are still warranted. Thus, strategies for re-designing police equipment and re-positioning it near the center of the body should be implemented within the police system, in order to minimize negative effects from the external load on the force and pressure distributions beneath the different foot regions. According to research by Quesada et al. (2000), there is a physiological impact of load carriage on the human body. Carrying an additional load equivalent to 15% of the body weight results in a 5-6% increase in metabolic cost. In our own study, we found that a 3.5 kg load, which represents a relative value for our sample, may not significantly increase metabolic costs. However, it can lead to a more pronounced forward lean and distort gait patterns, as indicated by Bobet & Norman (1984). While a 3.5 kg load may not seem substantial enough to induce negative changes in gait, our study revealed that it can lead to increased asymmetries during the gait cycle. Load carriage influences the antero-posterior and medio-lateral planes of the foot, resulting in higher ground reaction forces and plantar pressures, which could lead to discomfort and pain during walking, as noted in previous studies (Park et al., 2013; Goffar et al., 2013; Majumdar et al., 2013). Additionally, it may contribute to greater asymmetries between the left and right foot.

However, it's important to acknowledge the limitations of our study. The cross-sectional design restricts our ability to establish causal changes in asymmetries and limits the generalizability of our findings to police recruits. Furthermore, our focus on kinetic gait parameters means that we may have missed out on valuable insights provided by 3-D kinematic and electromyography systems. The absence of data pertaining to biological and physiological parameters, injury history, and load-carrying techniques further restricts the practical implications of our findings. Finally, the fact that participants walked barefoot over the pressure platform could have impacted on the observed gait patterns. Moving forward, it is essential for subsequent research to adopt a follow-up design and conduct comprehensive physiological and biomechanical analyses. Such studies should also consider load- and injury-related characteristics to mitigate the adverse effects of load carriage on gait.

10.4. Conclusions

Findings of this study indicate that ‘a 3.5-kg load’ significantly increases ground reaction force and plantar pressure gait asymmetries beneath the forefoot and midfoot regions, compared to ‘no load’ condition. Such asymmetries may have hazardous effects on gait stability and an increased likelihood for musculoskeletal injuries, due to foot pain and discomfort. These negative changes may impact foot placement on the ground and increase an incidence for future stress-fractures and deviated gait biomechanics in police recruits.

10.5. Author Contributions

Conceptualization, M.K. and L.Š.; methodology, L.Š.; software, L.Š.; validation, A.Š., M.K. and L.Š.; formal analysis, A.Š. and L.Š.; investigation, M.K.; resources, M.K.; data curation, L.Š.; writing—original draft preparation, A.Š., M.K. and L.Š.; writing—review and editing, A.Š., M.K. and L.Š.; visualization, L.Š.; supervision, M.K.; project administration, M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

10.6. Funding

This research received no external funding.

10.7. Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1, date: 3 July 2023).

10.8. Informed Consent Statement

All subjects gave their informed consent for inclusion before they participated in the study.

10.9. Data Availability Statement

The raw data supporting the conclusions of this article will be made available by the authors on request.

11. Conflicts of Interest

The authors declare no conflict of interest.

11.1. Acknowledgment

We would like to thank the Ministry of Internal Affairs and the principal Mr. Josip Ćelić (the chairman of the Police School department) for letting us conduct the study under their Institutional Committee approval.

11.2. RESEARCH STUDY THREE

Article title

Load Carriage and Changes in Spatiotemporal and Kinetic Biomechanical Foot Parameters during Quiet Stance in a Large Sample of Police Recruits

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11.3. ABSTRACT

Background

Little evidence has been provided regarding the effects of carrying a standardized load of equipment and foot parameters during quiet standing. Therefore, the main purpose of the study was to examine whether load carriage might impact static foot parameters in police recruits.

Methods

Eight-hundred and forty-five police recruits (27.9% women) were tested in 'no load' vs. a standardized '3.5-kg load' condition. Foot characteristics while standing were assessed with the Zebris FDM pedobarographic pressure platform.

Results

Carrying a 3.5-kg load significantly increased 95% confidence ellipse area ($\Delta = 15.0\%$, $p = 0.009$), center of pressure path length ($\Delta = 3.3\%$, $p = 0.023$) and average velocity ($\Delta = 11.1\%$, $p = 0.014$), length of minor axis ($\Delta = 8.2\%$, $p < 0.009$) and deviation in X ($\Delta = 12.4\%$, $p = 0.005$) and Y ($\Delta = 50.0\%$, $p < 0.001$) axes. For relative ground reaction forces, a significant increase in left forefoot ($\Delta = 2.0\%$, $p = 0.002$) and a decrease in left hindfoot ($\Delta = -2.0\%$, $p = 0.002$) were shown. No significant changes in relative ground reaction forces beneath forefoot and hindfoot regions for the right foot were observed ($p>0.05$).

Conclusion: 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.

Key words: special population, foot characteristics, center of pressure, statics, equipment, changes

11.4. Introduction

Load carriage is part of training and on-duty protocols tasks for special population, including military (Walsh & Low, 2021; Birrel et al., 2007) and police (Irving et al., 2019), representing a crucial component of survival. Although important, it has been observed that such load may impact on musculoskeletal system, causing an increased risk of lower limb injury (Wills et al., 2021) and lower physical performance (Boffey et al., 2019; Martin et al., 2023). Moreover, recent studies have observed a negative trend in load weight, often surpassing the recommended level of 45% body mass (Andersen et al., 2016; Orr et al., 2015).

When carrying heavy loads, gait and posture characteristics often tend to change and compensate for load added on the body (Fox et al., 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 et al., 2009). Indeed, the majority of previous evidence has tried to examine the effects of load carriage on foot parameters during gait; however, little evidence has been provided regarding carrying heavy loads and foot stability during quiet stance (Walsh & Low, 2021; Kasović et al., 2022a; Schiffman et al., 2006; Richmond et al., 2021). By carrying a load, a physiological component of an increased energy cost and fatigue has been often observed, increasing the risk of injuries and strains (Tahmasebi et al., 2015; Fallowfield et al., 2012). For quiet standing, deviations of center of pressure may be able predict future risk of injury and postural instability (Blacker et al., 2010), additionally causing ligamentous damage, especially in lower extremities (Knapik et al., 2004). Both cross-sectional (Reynolds et al., 1999) and longitudinal (Orr et al, 2015; Orr et al., 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 heavier loads increase center of pressure velocity and contact area between the foot and the ground, directly affecting on ground reaction forces beneath different foot regions (Walsh & Low, 2021; Strube et al., 2017).

The population of police officers is often required to perform their everyday tasks and duties at high level (Zwingmann et al., 2021). Their primary role includes serving and protecting the civilians against crime and are engaged in high-risk situations (Zwingmann et al., 2021). However, by carrying such a load for a long period of time, one could expect significant biomechanical gait changes, especially in a standing position, due to a different postural sway, which occurs by changing the body mass center away from the actual center and often leaning forward, causing greater forces beneath the different foot regions (Walsh & Low, 2021). Police recruits encounter carrying a specific external load for the first time, which may have negative effects on their body posture and related biomechanical parameters, causing pain and discomfort and often compensating for other body parts, especially in the contralateral directions (Strube et al., 2017). Due to the aforementioned biomechanical changes, it is necessary to examine spatiotemporal foot changes and relative ground reaction forces during quiet standing following a standardized load carriage. By examining such changes, policy makers would be able to act towards re-positioning and re-designing the police equipment to overcome its negative impact on health-related biomechanical foot parameters and adequate physiological energy expenditure important for everyday strenuous tasks and duties. The intention of newly developed equipment would give the possibility to be more efficient in the field during high-risk situations.

Therefore, the main purpose of the study was to examine differences in foot characteristics while standing still under two conditions: (i) “no load”, and (ii) ‘a 3.5 kg load’. We hypothesized that heavier loads would exhibit greater biomechanical foot changes and impaired balance, compared to the ‘no load’ condition.

11.5. Materials and methods

Study participants

In this cross-sectional study, we recruited police recruits, who were part of the one-year academy training program aiming to become a part of Croatian police service. A training program consists of monitoring and improving health-related physical fitness and learning everyday specific tasks and duties on the field. Technical and tactical parts of the program include handling a gun and behaving in high-risk situations, which is often accompanied by psychological preparation and the assessment of environment. All these tasks are completed while carrying out standardized police equipment on a daily basis. In general, a police academy recruits between 750 and 1,000 every year. From December 2023 till the first half of February 2024, when the study had been conducted, 900 police recruits were examined and selected to participate in the study. Since the academies' rules and regulation state that all recruits need to be without acute and chronic locomotor or psychological diseases, all eligible participants entered the study at the first stage. Of these, 55 were excluded, due to illness or musculoskeletal injury obtained during the training process. Thus, our final sample included in further analyses was based on 845 police recruits (27.9% women). All participants had been given information regarding general and specific aims, hypotheses, benefits and potential risks. All the procedures were anonymous and in accordance with the Declaration of Helsinki (World Medical Association, 2013). Furthermore, all participants gave written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

Load carriage

Standardized police load often includes a bulletproof vest and a belt accompanied with a full handgun and an additional handgun magazine consisting of 10 bullets, handcuffs and a nightstick. Based on the nature of this study and a recruitment of future police officers, the training protocol specifically dictates that they only need to have a standardized belt with the aforementioned equipment for physical and mental demands during the day, and the vest is often dismissed, due to many task assignments done with the upper body. Although previous evidence has examined the effects of a full load carriage on biomechanical foot parameters (Walsh & Low, 2021), for the purpose of this study, we selected standard police equipment carried during police training approximately 10-12 hours per day, which consisted of a belt (≈0.5 kg), a gun with a full handgun's magazine (≈1.5 kg), an additional full handgun's magazine (≈0.5 kg), a nightstick (≈0.8 kg) and handcuffs (≈0.2 kg). In total, the whole equipment without a police suit weigh ≈3.5 kg.

Static foot parameters

Measurements for all participants 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 weight. Ground reaction forces (absolute in N and relative in %) were measured. Each participant stepped 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 still (Gregory et al., 2017). The Zebris platform was connected via USB cable to an external unit (laptop). The data was gathered in real time using WinFDM software for 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 calibration of every single sensor automatically integrated into a platform. The task was to stand on the platform and maintain a calm position, with arms relaxed by the body and looking straight forward. After 15 sec 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 minor axis (X) (mm), (v) length of major axis (Y) (mm), (vi) deviation X, (vii) deviation Y, and (viii) the angle between Y and major axis (°). Specifically, the left and right points under each foot represent the respective area of the CoPs surrounded by the 95% CI. Inside the 95% CI area, the projection of the CoP and its velocity with an appropriate path length during a quiet stance is displayed. The length of minor axis denotes medio-lateral, while the length of major axis represents antero-posterior direction, while the angle between Y axis and a global y axis is described as the angle between major axis (Y) and global y axis pointing longitudinal orientation line of the platform. For ground reaction forces, the software generated data for the relative forces distributed under the forefoot and backfoot regions of the foot, as well as for the total foot (%). The ideal load distribution is often considered to be 50%-50% between the right and left standing surface, and the distribution load between the forefoot and heel is suggested to be 33% (1/3) on the forefoot, compared to 66% (2/3) on the heel. Of note, the vertical component of the ground reaction forces was collected and analyzed.

Statistical analysis

The Kolmogorov–Smirnov test to examine whether the data were significantly different from the Gauss distribution was used to assess the normality of the distribution. Since all the study variables were not normally distributed, i.e. were significantly different from the normal distribution, basic descriptive statistics of the study participants were presented as median with interquartile range (25^{th} percentile and 75^{th} percentile). Changes in biomechanical foot parameters during quiet standing with ‘no load’ vs. “a 3.5-kg load” were tested using the non-parametric Wilcoxon signed rank test for dependent sample, where differences were examined in one sample during the two measuring conditions: ‘no load’ vs. a ‘3.5-kg’ load. Although we tested spatiotemporal and kinetic foot parameters for both men and women, a preliminary analysis showed that there were no significant differences in changes between them (p = 0.230 – 0.768), so further analyses were based on a total sample. All statistical analyses were performed using the Statistical Packages for Social Sciences (SPSS. v23.0 software, IBM, Armonk, NY, USA) with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

11.6. Results

The initial sample of 845 individuals recruited at the beginning met all inclusion and exclusion criteria and no individual dropped out of the study during the assessment. In total, further analyses were based on 845 police recruits. Changes in static foot parameters under the different loading conditions are presented in Table 1. When carrying a '3.5-kg load', participants exhibited significantly higher values in confidence ellipse area (mean difference = 19.0 mm^2), center of pressure path length (mean difference = 3.0 mm) and average velocity (mean difference =10 mm/sec), length of minor axis (mean difference = 0.7 mm), deviation X (mean difference = 1.6 mm) and Y (mean difference = 1.8 mm). Insignificant spatiotemporal changes in length of major axis and the angle between Y and major axis were observed. For relative ground reaction forces beneath the different foot regions, carrying a '3.5-kg load' significantly increased relative average force beneath the left forefoot region, while a decrease in relative average force beneath the left hindfoot was shown. Interestingly, no significant main changes in right foot nor hindfoot were observed ($p > 0.05$).

Table 1. Basic descriptive statistics and changes in biomechanical static foot parameters under the different loading conditions in police recruits

Study variables	**'No load'**	**'A 3.5-kg load'**	**Δ (%)**	***p*-value**
Static parameters	**Median (25^{th} – 75^{th})**	**Median (25^{th} – 75^{th})**		
Confidence ellipse area (mm^2)	127.0 (76.5 – 236.0)	146.0 (85.0 – 253.0)	15.0%	**0.009**
Center of pressure path length (mm)	91.0 (64.5 – 127.0)	94.0 (69.0 – 134.0)	3.3%	**0.023**
Center of pressure average velocity (mm/sec)	9.0 (6.0 – 13.0)	10.0 (7.0 – 13.0)	11.1%	**0.014**
Length of minor axis (mm)	8.5 (6.3 – 12.0)	9.2 (6.9 – 12.5)	8.2%	**< 0.001**
Length of major axis (mm)	19.4 (14.6 – 27.2)	20.3 (15.2 – 26.9)	4.6%	0.201
Angle btw. Y and major axis (°) *	77.8 (66.4 – 84.4)	77.0 (62.8 – 84.7)	-1.0%	0.225
Deviation X (mm)	12.9 (4.0 – 23.5)	14.5 (2.0 – 26.2)	12.4%	**0.005**

Deviation Y (mm)	-3.6 (-9.95 – 3.10)	-1.8 (-9.7 – 5.6)	50.0%	**< 0.001**
Relative average force-left forefoot (%)	51.0 (47.0 – 55.0)	52.0 (48.0 – 56.0)	2.0%	**0.002**
Relative average force-left hindfoot (%)	49.0 (45.0 – 53.0)	48.0 (44.0 – 52.0)	-2.0%	**0.002**
Relative average force-left total (%)	47.0 (40.0 – 53.0)	46.0 (39.0 – 53.0)	-2.1%	0.345
Relative average force-right forefoot (%)	50.0 (46.0 – 54.0)	50.0 (45.0 – 55.0)	0.0%	0.714
Relative average force-right hindfoot (%)	50.0 (46.0 – 54.0)	50.0 (45.0 – 55.0)	0.0%	0.578
Relative average force-right total (%)	53.0 (47.0 – 60.0)	54.0 (47.0 – 61.0)	1.9%	0.285

***P* < 0.05**

11.7. Discussion

The main purpose of the study was to examine changes in foot characteristics while standing quiet under the two conditions: i) no load' vs. ii) a '3.5-kg load'. The main findings of the study are a) when carrying a '3.5-kg load', significant increases in confidence ellipse area, center of pressure path length and average velocity, length of minor axis, deviation X and Y are observed, and b) significant changes in relative ground reaction forces beneath the left forefoot and hindfoot regions are shown.

To the best of authors' knowledge, this is the first study aiming to investigate the effects of a '3.5-kg load' on spatiotemporal and kinetic foot parameters during quiet standing. 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, center of pressure path length, average velocity and lengths of minor and major axes with a decrease in the angle between Y and major axis (Kasović et al., 2022a; Strube et al., 2017; Kasović et al., 2022b). From a biomechanical perspective, evidence suggests that carrying heavier loads may 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; Strube et al., 2017). 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 increase postural sway. Besides biomechanical, the physiological effects of carrying heavy loads often result in larger heart rate frequency, respiratory changes and proprioceptive systems (Conforto et al., 2000; Kavounoudias et al., 1999).

In general, carrying heavy loads is an essential part of special populations. Along with its benefits, a negative trend of an increase in heavy loads led 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 compensation towards the initial position, steadily increasing the structure of the postural sway movements (Conforto et al., 2000; Kavounoudias et al., 1999). 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. With increased energy costs and repetitive force requirements, biomechanical changes in spinal loading, gait patterns and ground reaction forces may increase the risk of injuries, where knee, ankle and foot being the most affected body parts (Orr et al., 2015; Andersen et al., 2016). Due to a constant load and bone remodeling imbalances, repetitive bone loadings often lead to stress fractures connected to neurological injuries (Orr et al., 2021). Indeed, previous evidence suggests that previous injury is a risk factor for future injury, pointing out that individuals who experienced work-related injury are more prone for future injury and ambulatory treatment (Jones et al., 2010). Another risk factor for even more foot deviations is load distribution. 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 (Lenton et al., 2019).

This is one of the first study examining the effects of a '3.5- kg' load on spatiotemporal and kinetic foot parameters during quiet stance in a large sample of police recruits. Indeed, carrying heavy loads and determining its impact on biomechanical changes during walking (Walsh & Low, 2021) and standing (Strube et al., 2017) have been the topic in special population of military and police, pointing that heavy load may have negative impact on performance and overall body posture during completing everyday tasks and duties. On the other hand, the necessity of carrying equipment represents a crucial component of survival in often high-risk operations and situations. To overcome these reverse health benefits of load carriage, policy makers are keen to develop and implement differently re-positioned and managed loads on the body. For example, studies have shown that carrying a standardized backpack should be placed tight close to the center of mass to decrease anterior or lateral positions during walking or standing (Boffey et al., 2019). In Croatian police, a handgun is often carried on one side of the hip, which constantly disables the arm of that side of the body to swing naturally. Although we did not examine 3-D kinematics of upper body extremities, we observed that the 'affected' arm, both during walking and standing, is positioned further away from the trunk, because of the position of the handgun, leading the participants to lean to the other side and have the risk for scoliosis and numbness in the neck area and upper extremities. One potential mechanism of re-positioning the handgun is a lateral side of the thigh area, which could unable arms to move swiftly and repeatedly. Unfortunately, the policy in Croatia still states that the standardized police load needs to be worn around the hips, and with an additional effect of carrying such load between 10 and 12 per day may cause hazardous health-related outcomes in the future. Thus, special interventions and strategies aiming to change ergonomics and design of police equipment should be implemented within the police system, in order to adequately protect one's postural characteristics and utilize energy expenditure during walking and standing (Boffey et al., 2019).

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, 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. Based on the aforementioned limitations, future longitudinal studies 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.

11.8. Conclusions

In summary, this is the first study examining changes in spatiotemporal and kinetic static foot parameters under carrying a '3.5-kg load' vs. no load'. The findings of the study showed that an increased external load might increase confidence ellipse area, center of pressure path length and average velocity, length of minor axis, deviation X and Y, and forefoot and hindfoot regions of the left foot, while ground reaction forces beneath the right foot regions were not impacted by the load. Therefore, spatial and temporal parameters during quiet standing may be more prone to changes following an external load, compared to ground reaction forces, pointing out that future research should focus on foot characteristics, rather than forces being generated beneath the feet. The results of this study are important, due to the problem of wearing standard police equipment and its influence on spatiotemporal and kinetic parameters while standing. We believe that wearing the same equipment while walking would result in even greater negative biomechanical changes to the feet, and thus to the entire body, and future research must concentrate on studying the same effects during standardized tasks and in different physiological states, such as fatigue or sleep deprivation.

12. GENERAL CONCLUSION

In summary, this study shows that a "load of 3.5 kg/7.7 lb" can increase the asymmetry of the gait cycle during standing, load response, single limb support, and phases of pre-swing and swing, while the temporal parameter of step time asymmetry is also increased. These results imply that a standardized load carried by police recruits during preparatory training may have a negative impact on gait characteristics, particularly in terms of gait cycle and step time, suggesting that this device must be ergonomically redesigned to minimize the impact on the space-time parameters of the walk. Although our results showed small but significant effects of carrying a load of 3.5 kg / 7.7 lb, 5 kg / 7.7 lb "in gait parameters, especially gait cycles and step time, the practical value of the research can contribute to the reorganization of individual components of police equipment, with the aim to exhibit smaller asymmetries and to maintain similar biomechanical performance between the left and right sides of the In addition, by lowering the position of a gun on the surface of the thigh, individuals could move the arm quickly, tilting the trunk from the opposite position to a more neutral central position of the body and evenly redistributing the force applied on the ground.

Considering the general findings of the first study, we believe that future studies aimed at examining gait asymmetry during load carriage should focus on complete physiological and biomechanical analyses, subsequent design, and characteristics related to loading and injury. Future studies should also use 3-D kinematic and electromyographic systems to provide details on increased gait asymmetries under load. Furthermore, future research should collect biological and psychological data to examine the relationship between load carriage and dynamic foot parameters, and information on previous injuries. These factors may be key transfer factors to reduce the adverse effects of load carriage on gait.

This is the first study to examine changes in the static spatial and kinetic parameters of the leg when carrying a "3.5 kg load" compared to "free". The results of the study showed that increasing the external load could increase the area of the confidence ellipse, the length of the centre of the pressure path and the average speed, the length of the minor axis, the X and Y deviations and the average speed. in front and the posterior regions of the left leg, while the ground reaction forces under the regions of the right legwear not affected by the load.

Therefore, the spatial and temporal parameters during quiet stance may be more likely to change after the external load than the ground reaction forces, emphasizing that future research should focus on the characteristics of the foot rather than the forces generated under the foot The results of this study are important because of the problem of wearing standard police equipment and its impact on spatio-temporal and kinetic parameters during in we believe that wearing the same device while walking leads to even greater negative biomechanical changes in the foot and thus the whole body, and future research should focus on studying the same effects during standardized tasks and in different physiological states, such as fatigue or absence of sleep.

The results of this study show that a load of 3.5 kg significantly increased the ground reaction force and gait asymmetry under plantar pressure under the forefoot and midfoot regions, compared to a condition "no charge". Such asymmetries can have dangerous effects on the stability of walking and an increased probability of musculoskeletal injuries, due to the foot and discomfort. These adverse changes may affect foot placement and increase the incidence of future stress fractures and aberrant gait biomechanics in police recruits.

Future studies should modify the study design to examine longitudinal changes in static foot parameters during heavy load carrying. Also, as in the first and second studies, future studies should collect biological and physiological parameters as well as data related to injury history or load carrying.

12.1. Strengths and limitations

There are several strength points to this study. To the authors' knowledge, this is the first study to examine changes in asymmetry under different load conditions in police recruits. Although a load of 3.5 kg / 7. 7 lb does not appear to be high enough to produce negative gate changes, the results of this study indicate that it may increase asymmetries during the gait cycle, causing additional body disproportions and leading to path adjustments.

Nevertheless, there are some imperfections in this study. Due to a cross-sectional design, we cannot determine causal changes in asymmetry, limiting the generalizability of the results to police recruits who have not yet had experience with police duties and equipment. Second, we only examined spatial gait parameters, whereas 3D kinematic and electromyographic systems would have provided more information on increased gait asymmetry after "a load of 3.5 kg / 7 .7 lb. " spatial parameters of gait, while 3D kinematic and electromyographic systems had provided more information on increased gait asymmetry after "a load of 3.5 kg/7.7 lb." 5 kg / 7. 7 lb" and the inverse dynamic approach to test the torque at each joint. Third, we did not collect biological and physiological parameters, which could question dynamic foot parameters and load transport.

Finally, the participants walked barefoot on the pressure platform, potentially limiting generalizability and applicability of the results to the different daily activities of other populations in the sectors related to the police or military personnel.

12.2. Perspectives for future research

Given that carrying a load of 3.5 kg increased gait asymmetry and altered spatial and kinetic parameters, future studies should explore how ergonomic modifications to police equipment can minimize these effects. Future research could focus on testing alternative designs and load placements to balance biomechanical demands and reduce gait asymmetries.

Also, future studies could evaluate how different types of equipment or varying weights influence spatio-temporal gait parameters and ground reaction forces. Investigating thresholds at which load-related biomechanical disruptions become clinically significant could guide load management strategies in police training.

The study briefly mentions the importance of investigating the effects of fatigue and sleep deprivation on load-carrying biomechanics. Future research could investigate how carrying loads under various physiological conditions affects gait parameters, focusing on long-term fatigue or stress scenarios that more accurately mimic real-world police work.

As this study found significant changes in plantar pressure distribution and the impact on foot regions, more research could focus specifically on foot biomechanics during load-bearing activities. Investigating the effects of various footwear designs, foot orthotics, or equipment positioning on plantar pressure and foot placement could offer solutions to reduce stress fractures and other injuries.

Future studies could link the identified gait asymmetries and increased ground reaction forces to the long-term risk of musculoskeletal injuries, particularly stress fractures and joint degradation in police recruits. Research should also explore rehabilitation protocols or pre-training conditioning programs that mitigate the risks posed by these load-induced changes.

Since this study focused on static and kinetic parameters, further research could investigate dynamic aspects of load-bearing during more complex movements, such as running, jumping, or stair climbing. This would provide a more comprehensive understanding of how police equipment affects various movement patterns and whether interventions can stabilize gait across multiple scenarios.

Research could track police recruits over time to understand how the body adapts or deteriorates in response to prolonged use of standardized equipment. This would provide insights into whether the body compensates for load-induced gait changes or if these asymmetries worsen with time, leading to chronic conditions.

It would be beneficial to examine whether there are gender differences or individual variability in response to carrying loads, as body composition and biomechanics may influence how asymmetries manifest. Tailoring equipment based on individual biomechanics could be a crucial consideration for future ergonomic designs.

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14. LIST OF APPENDICIES

14.1. Study 1

Štefan, A., Kasović, M., & Štefan, L. (2024). Does a Standardized Load Carriage Increase Spatiotemporal Gait Asymmetries in Police Recruits? A Population-based Study. *Military medicine*, usae358. Advance online publication. https://doi.org/10.1093/milmed/usae358

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Does a Standardized Load Carriage Increase Spatiotemporal Gait Asymmetries in Police Recruits? A Population-based Study

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ABSTRACT

Introduction:

Although the effects of carrying loads on gait biomechanics have been well-documented, to date, little evidence has been provided whether such loads may impact spatial and temporal gait asymmetries under the different foot regions. Therefore, the main purpose of the study was to examine the effects of carrying a standardized police equipment on spatiotemporal gait parameters.

Materials and Methods:

In this population-based study, participants were 845 first-year police recruits (age: 21.2 ± 2.3 years; height: 178.1 ± 10.2 cm; weight: 78.4 ± 11.3 kg; body mass index: 24.7 ± 3.2 kg/m^2; 609 men and 236 women; 72.1% men and 27.9% women) measured in 2 conditions: (i) "no load" and (ii) "a 3.5 kg load." Spatiotemporal gait parameters were derived from the FDM Zebris pressure platform. Asymmetry was calculated as $(x_{right}—x_{left})/0.5*(x_{right} + x_{left})*100\%$, where "x" represented a given parameter being calculated and a value closer to 0 denoted greater symmetry.

Results:

When compared to "no load" condition, a standardized 3.5 kg/7.7 lb load significantly increased asymmetries in spatial gait parameters as follows: gait phases of stance (mean diff. = 1.05), load response (mean diff. = 0.31), single limb support (mean diff. = 0.56), pre-swing (mean diff. = 0.22), and swing (mean diff. = 0.90) phase, while no significant asymmetries in foot rotation, step, and stride length were observed. For temporal gait parameters, we observed significant asymmetries in step time (mean diff. = –0.01), while no differences in cadence and gait speed were shown.

Conclusions:

The findings indicate that the additional load of 3.5 kg/7.7 lb is more likely to increase asymmetries in spatial gait cycle components, opposed to temporal parameters. Thus, external police load may have hazardous effects in increasing overall body asymmetry, which may lead to a higher injury risk and a decreased performance for completing specific everyday tasks.

INTRODUCTION

Carrying an external load during everyday tasks represents a major component of physical activity of police officers.[1] Although such load may be a crucial for protection and high-level performance,[2] an intercorrelation between an individual, load, and specific field-based duties may be considered to interact and affect one's health and well-being.[3] A 2-way approach of investigating the effects of load carriage on health status has often been proposed, focusing on physiological[2,4] and biomechanical changes.[2,5] In physiological studies, the load carried and speed of the march have been primarily responsible for energy expenditure changes,[2] while in the field of biomechanics, heavy load increases trunk, hip, and knee flexion and hip and knee extension moments, while limited effects on spatiotemporal and kinetic gait parameters are observed.[5]

Naturally, differences in the bilateral behavior, often referred as "body asymmetry," have raised a great attention in recent years.[6–9] Although a healthy asymmetry between 5 and 15% has been identified as the upper threshold for adequate strength performance,[7] one would expect that the additional load carriage might increase differences between the sides of the body for up to 50%.[10] For lower extremities, studies have predominately wanted to examine whether the asymmetrical load carriage tends to have an effect on biomechanical gait parameters.[6,8–12] In general, an uneven load increases hip and knee extensor moments of the unloaded leg,[11] changing knee biomechanics.[9,13] However, little evidence has been provided regarding carrying load and gait asymmetry.[10] For example, a study by Zhang et al.[10] has shown that asymmetry in ground reaction forces in medio-lateral direction is significantly greater under 20% body weight conditions, compared to 0 to 10% conditions. Indeed, the asymmetrical changes

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under different load conditions come from inertial characteristics of locomotor system and the restriction of natural arm swing patterns.[14]

To the best of authors' knowledge, there has been lack of studies examining the effects of carrying load on spatiotemporal gait characteristics. Since carrying police equipment may cause larger foot rotation, decreases in step and stride length and increases in step and stride time,[15] it is reasonable to hypothesize that such load can produce even larger gait asymmetries. From a practical point of view, load carriage may increase the incidence of musculoskeletal injury rate[16,17] and stress syndrome,[18] which may limit duty time and increase the odds for hospitalization.[19] Also, it would be possible for policy makers to re-design the existing police load and redistribute necessary load parts to decrease gait asymmetry.

Given the importance of symmetrical gait during completion of everyday tasks and assignments, one would expect that additional load might produce changes in spatial and temporal gait parameters and directly impact on gait asymmetries. Such uneven values on the left and right sides of the body could possibly lead to changes in body posture and a decrease in performance, and even to a higher risk of injuries. On the other hand, examining how body asymmetry changes under a certain loading condition could give a meaningful insight of re-structuring/organizing the existing load, so it produces less hazardous biomechanical effects on the body during walking. Finally, public health policy makers may expand the knowledge of safety issues of the load and how the findings may be implemented to other occupations, which are at higher risk of excessive load carriage.

Therefore, the main purpose of the present study was to examine whether standardized equipment produced greater spatiotemporal gait asymmetries in a large sample of police recruits. Since external load of police officers is not unique for both sides of the body, we hypothesized that an external load being carried by police officers might produce greater spatial and temporal gait asymmetries, especially during different gait cycles and unilateral/bilateral support between the body and the ground.

MATERIALS AND METHODS

Study Participants

In this cross-sectional study, we recruited police recruits, who were part of the 1-year academy training program aiming to become a part of Croatian police service. A training program consists of monitoring and improving health-related physical fitness and learning everyday specific tasks and duties on the field. Technical and tactical parts of the program include handling a gun and behaving in high-risk situations, which is often accompanied by psychological preparation and the assessment of environment. All these tasks are completed while carrying standardized police equipment on a daily basis. In general, a police academy recruits between 750 and 1,000 every year. In 2022, when the study had been conducted, 900 police recruits were examined and selected to participate in the study. The inclusion criteria strictly stated that all participants needed to be without locomotor and mental acute or chronic diseases, which could prevent them from taking part in the study. Also, each participant had to be in the training program of police academy and should attend planned programs, tasks, and assignments on a regular basis. The exclusion criteria included participants suffering from locomotor (injury) or mental (depression or any other disease) and who were ill at the time the study had been conducted. All participants had been given information regarding general and specific aims, hypotheses, benefits, and potential risks. All the procedures were anonymous and in accordance with the Declaration of Helsinki. Furthermore, all participants gave written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy "Josip Jovic" and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

Load Equipment

For the purpose of this study, we selected standard police equipment carried during police training, which consisted of a belt (≈0.5 kg; 1.1 lb), a gun with a full handgun's magazine (≈1.5 kg; 3.3 lb), an additional full handgun's magazine (≈0.5 kg; 1.1 lb), a nightstick (≈0.8 kg; 1.8 lb), and handcuffs (≈0.2 kg; 0.5 lb). In total, the whole equipment without a police suit weighs ≈3.5 kg (7.7 lb). Of note, the participants wore the 3.5 kg load on a daily basis, but only when specific tasks and assignments were conducted with a duration of approximately 4 h/d. The intention of wearing the load on a daily basis was because the participants got familiar with the design and the feeling of carrying an external load on one side, and how they would complete the police program and given tasks and assignments in specific, real-life situations when carrying it on other side.

Spatiotemporal Gait Analysis

In order to calculate spatiotemporal gait parameters, we tested all the study participants with the Zebris pedobarographic platform (FDM; GmbH, Munich, Germany; number of sensors: 11.264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm), a multisensory device aimed to record, process, and generate gait characteristics in dynamic (walking) and static (quiet standing) conditions. The platform was positioned on the ground with additional custom-made wooden platforms (each 4.5 meter in length) placed before and after the Zebris platform to make the walking surface even. The testing procedure included each participant to walk normally at a comfortable speed and without shoes over the first wooden platform to gain an adequate acceleration and gait pattern, reaching to the pressure platform to collect the data and finishing on the second wooden platform to decelerate, after which the participant stopped at the end of a walkway, turned around for 180°, and continued to walk over the platforms to the starting point. The condition of walking without shoes was used because the design of shoes worn by police recruits is specific, due to the fact that the sole of the shoe is about 2 to 3 centimeters thick, and based on this, it can absorb a certain amount of forces and pressures under certain regions of the foot, which directly affects the spatial and temporal parameters of gait. Also, the same methodology has been used previously in a similar sample.[15] This task was completed 8 times.[20] After completing the first task, the same task was repeated while carrying police equipment. The software generated the data regarding foot rotation (°, measured as the position of both feet on the ground while walking and being compared to the platform, where the angle between each foot placement and the platform served as the foot rotation), step length (cm), stride length (cm), step width (cm), gait cycle phases (%, stance, load response, single limb support, pre-swing, swing, and double support), step time (s), stride time (s), cadence (steps/min), and walking speed (km/h).

Table 1. Basic descriptive statistics of the study participants.

Variables	Mean (SD)/N (%)	Min—Max	Range
Sex			
Men	609 (72.1%)		
Women	236 (27.9%)		
Age (years)	21.3 ± 2.1	18.7–24.7	6.0
Height (cm)	175.2 ± 14.3	164.3–190.8	26.5
Weight (kg)	74.4 ± 14.5	57.3–100.6	43.3
Body mass index (kg/m^2)	24.3 ± 4.8	19.4–28.3	8.9
Nutritional status (%)			
Normal weight ($<25\,kg/m^2$)	710 (84.0%)		
Overweight ($<30\,kg/m^2$)	93 (11.0%)		
Obesity ($\geq 30\,kg/m^2$)	42 (5.0%)		
Socioeconomic status (%)			
Below average	245 (29.0%)		
Average	450 (53.3%)		
Above average	150 (17.7%)		

Statistical Analysis

Kolmogorov-Smirnov test was used to assess the normality of the study variables. Basic descriptive statistics of the study participants are presented as mean and SD for normally distributed variables and median and interquartile range (25th and 75th percentile) for not normally distributed variables. Accordingly, differences in gait characteristics between "no load" vs "a 3.5 kg/7.7 lb load" were examined using Student *t*-test for dependent sample (1 sample in 2 load conditions) or Wilcoxon signed-rank test. Since each participant completed the task 8 times for a given parameter, we calculated the differences between each trial using the repeated measures analysis of variance and investigated internal reliability using cross-correlation analysis with Cronbach's alpha and the coefficient of variation. The reason for such approach was using the mean and SD of all 8 trials for a single spatial and temporal gait parameter. The same methodology has been previously described[20] and used[15] in similar populations. No significant differences between the trials in spatial and temporal gait parameters were observed (P = .583–.873), Cronbach's alpha showed excellent internal reliability (0.87–0.96) with a coefficient of variation of 1.1%, indicating that mean with SD were appropriate descriptive statistics for further analyses. Gait asymmetries were calculated using the formula proposed by Robinson et al.[21]: $(x_{right}–x_{left})/0.5*(x_{right} + x_{left})*100\%$, where "x" represented a given parameter being calculated. A score of 0 denotes perfectly symmetric gait, and as the value increases in positive or negative direction, asymmetry increases. The statistical significance was set at a priori $P \leq .05$. For the purpose of examining the effects of "a 3.5-kg/7.7 lb load" vs "no load" on spatial and temporal gait parameters, we additionally calculated Cohen's D effect sizes (ES) and interpreted them as small (0.2), medium (0.5), and large (0.8).[22] All analyses were performed in Statistical Packages for Social Sciences (SPSS Inc., Chicago, IL, USA).

RESULTS

At the beginning, 900 participants were eligible to be part of the study. Based on inclusion and exclusion criteria, 55 were excluded due to illness or musculoskeletal injury obtained during the training process. Thus, our final sample included in further analyses was based on 845 (93.4% of the initial sample) police recruits ([mean ± SD]; age: 21.2 ± 2.3 years; height: 178.1 ± 10.2 cm; weight: 78.4 ± 11.3 kg; body mass index: 24.7 ± 3.2 kg/m^2; 609 men and 236 women; 72.1% men and 27.9% women). Basic descriptive statistics of the study participants are presented in **Table 1**. Roughly 2/3 of the study participants were men (N = 609; 72.1%), opposed to 27.9% women (N = 236). All the study participants were categorized as young adults between ages 18 and 25 years of age, with a "normal" body mass index. Most of the participants rated their socioeconomic status as "average."

Changes in spatial and temporal gait parameters are presented in **Table 2**. In general, no significant differences in spatiotemporal gait parameters between "no load" vs "a 3.5-kg/7.7 lb load" were observed. However, significant differences in load response phase for the right foot, pre-swing phase for the left foot, swing phase for the right foot, and step time for the right foot were observed. Of note, to determine whether sex had a significant impact on changes in spatial and temporal gait parameters, a time × sex interaction for each of the study variable was calculated. In further analyses, we found no significant time × sex interaction in asymmetries of spatial gait parameters for foot rotation ($F_{1,833} = 0.555$, $P = .320$), step length

Table 2. Gait spatiotemporal descriptive statistics of the study participants.

Study variables	"No load" Mean (SD)	"a 3.5-kg/7.7 lb load" Mean (SD)	*P*-value
Foot rotation (°)			
Left foot	6.16 (6.50)	5.61 (6.98)	.131
Right foot	8.60 (6.88)	8.23 (6.27)	.291
Step length (cm)			
Left foot	64.94 (6.28)	65.04 (6.27)	.754
Right foot	64.61 (6.16)	64.59 (5.98)	.930
Step width (cm)	12.80 (3.06)	12.65 (3.01)	.301
Gait cycle components			
Stance (%)			
Left foot	62.28 (3.19)	62.37 (2.49)	.538
Right foot	62.31 (2.52)	62.51 (2.43)	.125
Load response (%)			
Left foot	12.42 (2.85)	12.40 (1.97)	.858
Right foot	12.40 (2.04)	12.64 (1.98)	.026
Single limb support (%)			
Left foot	37.55 (2.88)	37.34 (2.75)	.156
Right foot	37.51 (2.30)	37.49 (2.28)	.894
Pre-swing (%)			
Left foot	12.46 (1.92)	12.75 (2.50)	.017
Right foot	12.40 (1.88)	12.46 (1.86)	.578
Swing (%)			
Left foot	37.62 (2.58)	37.55 (2.14)	.590
Right foot	37.71 (2.55)	37.45 (2.13)	.024
Double stance phase (%)	25.08 (7.77)	25.11 (3.25)	
Step time (s)			
Left foot	0.56 (0.04)	0.56 (0.04)	.708
Right foot	0.56 (0.04)	0.56 (0.04)	.050
Stride time (s)	1.31 (0.15)	1.32 (0.15)	.966
Cadence (steps/min)	108.09 (19.23)	108.37 (14.0)	.857
Walking speed (km/h)	4.25 (2.05)	4.64 (1.56)	.371

($F_{1,833}$ = 0.125, P = .723), stance ($F_{1,833}$ = 1.047, P = .187), load response ($F_{1,833}$ = 0.944, P = .235), single limb support ($F_{1,833}$ = 1.047, P = .187), pre-swing ($F_{1,833}$ = 0.745, P = .411), swing ($F_{1,833}$ = 0.226, P = .187), and double stance phase ($F_{1,833}$ = 1.233, P = .99) of the gait. For temporal gait parameters, no significant time × sex interaction for asymmetries for step time ($F_{1,833}$ = 1.445, P = .065), stride time ($F_{1,833}$ = 1.399, P = .071), cadence ($F_{1,833}$ = 0.887, P = .722), and gait speed ($F_{1,833}$ = 0.744, P = .756) were found. Therefore, the results were presented as combined values of men and women, respectively.

Table 3 shows symmetry indexes for spatiotemporal gait parameters. When carrying "a 3.5-kg/7.7 lb load," participants significantly increased their asymmetries in gait cycle phases, especially in stance (ES = 0.14), load response (ES = 0.13), single limb support (ES = 0.10), pre-swing (ES = 0.24) and swing (ES = 0.20) gait cycles, and step time (ES = 0.15), while no significant asymmetry changes with trivial effects in other parameters were observed (P > .05). Also, no significant changes occurred in step width, double stance phase, stride time, cadence, and walking speed.

DISCUSSION

The main purpose of the present study was to examine whether standardized equipment produced greater spatiotemporal gait asymmetries in a large sample of police recruits. The main findings of the study are: (i) "a 3.5-kg/7.7 lb load" significantly increases asymmetries in gait cycle, especially for stance, load response, single limb support, pre-swing, and swing phases; and (ii) asymmetry index in step time also increases, following "a 3.5- kg/7.7 lb load," compared to "no load" condition. Based on the aforementioned findings, the hypothesis of an increased spatial gait asymmetry when carrying "a 3.5 kg/7.7 lb" load can be accepted, especially when the results are observed in terms of different gait cycles. For temporal gait parameters, only the asymmetry in step time is observed, meaning that the second hypothesis can be partially accepted.

To the best of authors' knowledge, this is the first study examining asymmetry differences during different load conditions in police recruits. Indeed, a common method to define gait asymmetry between the left and right feet has been by measuring ground reaction forces, often in stance position.[19,23] The findings of these studies have suggested that between 65 and 75% of respondents are asymmetrical, especially in vertical and medial/lateral direction.[23] However, an asymmetrical analysis during gait has been less studied.[10] In a study by Zhang et al.,[10] the asymmetry in ground reaction forces increased after additional load, indicating that such load might cause different effects in the left and right foot. Although the aforementioned study did not assess spatiotemporal gait parameters, increased asymmetry in gait cycle phases obtained in this study could be explained by cumulative effects of changing the inertial patterns of musculoskeletal system and the restriction of natural arm swing because of load characteristics and lateral trunk position.[14,24] For example, previous evidence suggests that the trunk often deviates away from the loaded side, pointing out that motor control actions following external load might be associated to strategies of load carriage and load characteristics, including weight and shape.[10] Postural adaptations between the left and right side of the body are due to a preferred handedness and changes in neuromuscular system. Although the mechanism underlying gait asymmetries is because of stride length, cadence, and walking speed,[2] we observed no significant changes in these parameters following "a 3.5-kg/7.7 lb load," expanding the understanding of asymmetry increases to other factors, including load patterns and physiological adaptations.[2] In this study, "a 3.5-kg/7.7 lb load" had small but significant effects on gait asymmetry, but these changes were likely to be explained by load placement[25] and higher energy

Table 3. Symmetry indexes for spatiotemporal gait parameters based on the left and right side of the body.

	"No load"	"a 3.5-kg load"			
Study variables	**Mean (SD)**	**Mean (SD)**	**Mean diff.**	**95% mean diff.**	***P*-value**
Foot rotation (°)	0.82 (4.23)	0.54 (3.16)	0.29	−0.11 to 0.68	.153
Step length (cm)	−0.82 (12.85)	−1.21 (13.05)	0.39	−0.98 to 1.76	.580
Stance (%)	−0.01 (8.14)	1.04 (6.68)	−1.05	−1.83 to −0.26	.009
Load response (%)	−0.09 (3.26)	0.21 (1.03)	−0.31	−0.56 to −0.05	.020
Single limb support (%)	−0.12 (4.85)	0.44 (4.62)	−0.57	−1.06 to −0.06	.030
Pre-swing (%)	−0.03 (0.90)	−0.25 (1.60)	0.22	0.08 to 0.37	.002
Swing (%)	−0.16 (5.02)	0.74 (4.03)	−0.90	−1.38 to −0.42	<.001
Step time (s)	0.00 (0.00)	−0.01 (0.00)	−0.01	−0.01 to −0.02	.020

expenditure.[26] The most appropriate way of carrying a load is via backpack, keeping the load near the center of gravity.[27] In police recruits, load characteristics include placing a handgun to the dominant side of the body. Even though the effectiveness of such position has merit, by sticking out, the subject often tends to compensate body posture by limited arm swing on the side the handgun is placed and lowering the opposite shoulder for better frontal propulsion.[2] From a physiological point of view, Quesada et al.[26] showed that an increase in load carriage by 15% body weight increased metabolic cost by 5 to 6%. While a relative value of "a 3.5-kg/7.7 lb load" was around 5% for our sample, which might not be enough to produce higher metabolic cost, a low load has been shown to cause a more drastic forward lean, which can further distort gait patterns.[28]

Although a load carriage of 3.5 kg/7.7 lb may not seem to be high enough to produce negative gate changes, the findings of this study showed that it might increase asymmetries during gait cycle, causing additional body disproportions and embracing poor gait adjustments. Loss of stability during gait while carrying load primarily affects antero-posterior and medio-lateral planes of the foot,[5] increasing ground reaction forces and plantar pressures and leading to possible discomfort and pain during walking. In that way, the discrepancy between the left and right foot may increase, potentially leading to greater asymmetries in gait parameters.[29–31]

This study is not without limitations. Due to a cross-sectional design, we cannot determine causal changes in asymmetries, limiting the generalizability of the findings to police recruits, who were still not experienced to police tasks and equipment. Second, we only examined spatiotemporal gait parameters, while 3-D kinematic and electromyography systems would have given more information regarding increased gait asymmetries following "a 3.5-kg/7.7 lb load." Third, we did not collect biological and physiological parameters, which may interrogate between dynamic foot parameters and load carriage. Also, collection of data regarding injury history or how load was carried was not collected, limiting the possibility to expand our findings to practical implications toward re-positioning load items and exploring potential effects of load carriage on the incidence of injuries. Finally, participants walked barefoot over the pressure platform, which might have affected gait patterns. Thus, future research aiming to examine gait asymmetries during load carriage should focus on follow-up design and complete physiological and biomechanical analyses, load- and injury-related characteristics, which may be important communicable factors for limiting negative effects of load carriage on the gait.

CONCLUSIONS

In summary, this study shows that "a 3.5-kg/7.7 lb load" may increase gait cycle asymmetries during stance, load response, single limb support, pre-swing, and swing phases, while temporal parameter of step time asymmetry is also increased. These findings imply that a standardized load worn by police recruits during preparation training may have negative impact on gait characteristics, especially in terms of gait cycle and step time, which suggests that such equipment should be ergonomically re-designed to minimize the impact on spatiotemporal gait parameters. Although our findings showed small but significant effects of carrying a load of "a 3.5 kg/7.7 lb" on gait parameters, especially in gait cycles and step time, the practical value of the research could contribute to the re-organization of individual components of police equipment, with the aim of the appearance of smaller asymmetries and the maintenance of similar biomechanical performance between left and right side of the body. Also, by lowering the position of a handgun on the thigh surface, individuals would be able to move the arm swiftly, leaning the trunk from the opposite to the more neutral position of the body center and evenly re-distribute the applied force on the ground.

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INSTITUTIONAL REVIEW BOARD (HUMAN SUBJECTS)

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).

INDIVIDUAL AUTHOR CONTRIBUTION STATEMENT

AŠ and LŠ collected and analyzed the data and drafted the original manuscript. MK and LŠ designed this research, reviewed and edited the manuscript. All authors read and approved the final manuscript.

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None declared.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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14.2. Study 2

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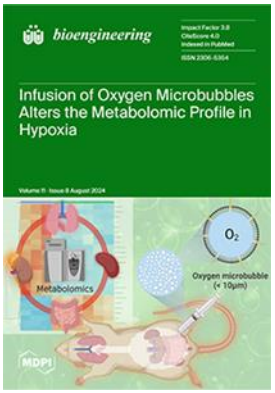

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Article

Carrying Police Load Increases Gait Asymmetry in Ground Reaction Forces and Plantar Pressures Beneath Different Foot Regions in a Large Sample of Police Recruits

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Abstract: Background: Although carrying external load has negative effects on gait biomechanics, little evidence has been provided regarding its impact on body asymmetry. The main purpose of the present study was to examine, whether standardized equipment produced greater gait asymmetries in ground reaction force and plantar pressure. Methods: For the purpose of this study, we recruited 845 police recruits (609 men and 236 women; 72.1% men and 27.9% women) measured in two conditions: (i) 'no load' and (ii) 'a 3.5 kg load'. Absolute values in ground reaction forces and plantar pressures beneath the different foot regions were assessed with pedobarographic platform (Zebris FDM). Asymmetry was calculated as $(x_{right} - x_{left})/0.5 \times (x_{right} + x_{left}) \times 100\%$, where 'x' represented a given parameter being calculated and a value closer to 0 denoted greater symmetry. Results: Significant differences in ground reaction forces and plantar pressures between the left and right foot were observed, when adding 'a 3.5 kg load'. Compared to the 'no load' condition, carrying 'a 3.5 kg load' significantly increased gait asymmetries for maximal ground reaction forces beneath the forefoot (ES = 0.29), midfoot (ES = 0.20) and hindfoot (ES = 0.19) regions of the foot. For maximal plantar pressures, only the asymmetry beneath the midfoot region of the foot significantly increased (ES = 0.19). Conclusions: Findings of this study indicate that 'a 3.5 kg load' significantly increases ground reaction force and plantar pressure gait asymmetries beneath the forefoot and midfoot regions, compared to 'no load' condition. Due to higher loads, increases in kinetic gait asymmetries may have negative effects on future pain and discomfort in the foot area, possibly causing stress fractures and deviated gait biomechanics in police recruits.

Keywords: special populations; police equipment; load carriage; symmetry; effect size

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1. Introduction

Load carriage in special populations, like police officers, is considered a crucial component of everyday physical activity and successful performance of occupational tasks [1,2] Although such load may have beneficial effects for on-duty protection and completing the tasks at maximal level [3,4], previous research has highlighted negative effects of the load on one's health and well-being (Salvendy, 2012), primarily focusing on physiological [3,5] and biomechanical changes [3,4]. In the field of physiology, carrying an external load and gait propulsion may produce higher energy expenditure [3]. On the other hand, from a biomechanical point of view, added mass to body weight may increase moments in the trunk, hip and knee flexion and extension areas, while inconclusive data between the load carriage and ground reaction forces and plantar pressures are detected [4]. Both physiological and biomechanical consequences of carrying heavy loads can also increase the fatigue [6] and the incidence of musculoskeletal injuries [7,8].

Studying gait symmetry has often been a topic of interest for healthcare professionals to detect gait characteristics in normal population [9] and identifying injury risk [10]. A 'perfect symmetry', indicating an equal degree for a given parameter between the left and right foot, has been set to be between 5 and 15% for some motor abilities, like strength [11]; it is reasonable to expect that carrying loads may naturally affect gait asymmetry for up to 50% [12]. With that in line, available studies have shown that carrying an extra load potentially increases hip and knee extensor moments of the unloaded leg [13], changing knee biomechanics [14,15]. Although a common method for assessing the degree of symmetry has been by measuring ground reaction forces [12], the majority of previous studies have investigated the effects of external load on ground reaction force and plantar pressure gait asymmetries during quiet stance [16,17], with limited information for such a phenomenon during gait [12]. A study by Zhang et al. [12] has concluded that carrying a load of 20% body mass increases ground reaction force asymmetries in a mediolateral plane, compared to 0 to 10% conditions. Indeed, an increased gait asymmetry and body compensations following load carriage come from inertial characteristics of the musculoskeletal system [18].

To the best of the authors' knowledge, there has been a lack of studies examining the effects of load carriage on gait asymmetries in terms of ground reaction forces and plantar pressures. Since 'a perfect symmetry' between the sides of the body without carrying a load does not exist, we can speculate that an additional mass added onto the body may even increase gait asymmetry in the aforementioned gait parameters. Indeed, a higher level of ground reaction forces and plantar pressures have been constantly associated with a higher incidence of musculoskeletal injury rate [19,20], which can increase and prolong hospitalization time [21]. Although a load carriage is a necessity for special populations, redistributing load items on the body may be a crucial part for minimizing negative impacts on gait biomechanics.

Therefore, the main purpose of the present study was to examine whether standardized equipment produced greater ground reaction force and plantar pressure gait asymmetries in a large sample of police recruits. We speculated that such loads might increase ground reaction force and plantar pressure asymmetries, especially beneath the hindfoot and forefoot regions.

1. Materials and Methods

1.1. Study Participants

For the purpose of this study, we recruited 900 police recruits, who were part of the Croatian police service at the time. More detailed information about recruitment, sample size characteristics, inclusion and exclusion criteria and data regulations can be found elsewhere [22]. In brief, every year, a police academy recruits and welcomes around 900 healthy men and women, who undertake a special police training program in the duration of one year. In 2023, we were able to recruit all 900 first-year police recruits for our study and 845 of them had eligible data for further analyses (27.9% women). The inclusion criteria included from all participants to be without locomotor and mental acute or chronic diseases, which could prevent them from taking part in the study, and to be in the training program of the police academy on a regular basis. The exclusion criteria included participants suffering from locomotor (injury) or mental (depression or any other disease) and who were ill at the time the study had been conducted. Before the study had been conducted, all participants became familiar with aims, hypotheses, benefits and potential risks of the study and how the findings might translate into practice. Following the Declaration of Helsinki procedure, all analyses were anonymous and all participants gave a written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

1.1. Load Equipment

A standardized load equipment being carried by police recruits involved a belt with a gun and a full handgun's magazine, an additional full handgun's magazine, a nightstick and handcuffs, where the final weight was around 3.5 kg (7.7 Ibs) [22,23].

1.2. Ground Reaction Forces and Plantar Pressures

Ground reaction forces and plantar pressures beneath different foot regions were analyzed via an objective method of the Zebris pedobarographic platform (FDM; GmbH, Munich, Germany; number of sensors: 11.264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm). The device uses a multisensory principle which may capture spatiotemporal and kinetic gait characteristics during walking or standing positions. More detailed information of testing the protocols and generating the data can be found elsewhere [22,23]. In brief, each participant walked at a preferred gait speed over the platform eight times, after being instructed not to target the platform or change the patterns of the walk. After completing the first task, the same task was repeated while carrying police equipment. The kinetic gait parameters included generating the data regarding maximal ground reaction forces (N) and plantar pressures (N/cm^2) of the left and right foot of the body for the forefoot, midfoot and hindfoot regions.

1.3. Data Analysis

All procedures were analyzed using Statistical Packages for Social Sciences software version 23 (SPSS Inc., Chicago, IL, USA). First, to test the normality of the study variables, we used the Kolmogorov–Smirnov test. For normally and not normally distributed variables, descriptive statistics are presented as mean and standard deviation (SD) or median and interquartile range (25th and 75th percentile). Student t-test for dependent samples or Wilcoxon singed-rank test were used to examine differences between 'no load' vs. 'a 3.5 kg load'. To examine gait asymmetries, we used the formula proposed by Robinson et al. [24]: $(x_{right} - x_{left})/0.5 \times (x_{right} + x_{left}) \times 100\%$, where an 'x' represented a given parameter. A final score closer to 0 denotes a more symmetrical gait, while a score that deviates more from 0 denotes greater asymmetry. Effect size (ES) was used to express the magnitude of the difference between groups and was presented as 'small' (0.2), 'moderate' (0.5), 'large' (0.8) [25]. To test, whether gender had any effects on kinetic gait changes, we used repeated-measures ANOVA with gender as a between-group factor and found no significant interaction between time and gender in any of the studied variables, so we omitted sex-specific presentation of the data. Also, age and body mass index were not significantly correlated to ground reaction force and plantar pressure changes. The significance was set at a priori $p \leq 0.05$.

2. Results

Socio-demographic characteristics of the study participants are presented in Table 1. The data of Table 1 relied on one previous study published by the same authors [22].

Table 1. Basic descriptive statistics of the study participants at baseline.

Variables	Mean (SD)/N (%)	Min–Max	Range
Gender			
Men	609 (72.1%)		
Women	236 (27.9%)		
Age (years)	21.3 ± 2.1	18.7–24.7	6.0
Height (cm)	175.2 ± 14.3	164.3–190.8	26.5
Weight (kg)	74.4 ± 14.5	57.3–100.6	43.3
Body Mass Index (kg/m^2)	24.3 ± 4.8	19.4–28.3	8.9

Changes in ground reaction forces and plantar pressures are presented in Table 2. When carrying 'a 3.5 kg load', significant differences in ground reaction forces for left forefoot (Δ = 2.9%), left midfoot (Δ = 3.6%), right midfoot (Δ = 3.6%) and right hindfoot (Δ = 1.7%) were observed. For plantar pressures, a load of 3.5 kg significantly increased the area beneath the left forefoot (Δ = 2.0%), right forefoot (Δ = 1.2%) and right midfoot (Δ = 0.4%). Finally, the % of time maximal force during stance time was significantly increased beneath the left forefoot (Δ = 0.5%) and right midfoot (Δ = 0.8%), while a significant decrease in left midfoot was shown. Changes in gait asymmetries according to gender showed no significant time* gender interactions for ground reaction forces beneath the forefoot ($F_{1,833}$ = 0.616, p = 0.433), midfoot ($F_{1,833}$ = 0.347, p = 0.556) and hindfoot ($F_{1,833}$ = 0.750, p = 0.387) regions of the foot. Also, when force was applied to a surface as a plantar pressure, we observed no significant time* gender interaction for asymmetries beneath the forefoot ($F_{1,833}$ = 0.743, p = 0.392), midfoot ($F_{1,833}$ = 0.422, p = 0.588) and hindfoot ($F_{1,833}$ = 0.255, p = 0.650) regions of the foot.

Table 2. Gait changes (mean ± SD) in ground reaction forces and plantar pressures beneath different foot regions.

Study Variables	Load Condition		*t*-Value	*p*-Value
	'No Load'	'a 3.5 kg Load'		
Sex, N (%)				
Men/Women	609 (72.1%)/ 236 (27.9%)	609 (72.1%)/ 236 (27.9%)	0.000	1.000
Age (years)	21.3 ± 2.1	21.3 ± 2.1	0.000	1.000
Body Mass Index (kg/m²)	24.3 ± 4.8	25.4 ± 4.5	−2.176	0.037
Maximal Ground Reaction Forces				
Left Foot				
Forefoot (N)	758.58 (130.70)	780.44 (135.94)	−3.351	< 0.001
Midfoot (N)	145.58 (71.58)	150.83 (78.34)	−2.083	0.037
Hindfoot (N)	513.65 (98.57)	524.38 (98.53)	−1.432	0.152
Right Foot				
Forefoot (N)	766.11 (304.00)	798.78 (336.76)	−1.497	0.135
Midfoot (N)	156.84 (79.10)	162.52 (76.32)	−2.227	0.026
Hindfoot (N)	500.23 (98.86)	508.53 (98.31)	−1.923	0.045
Maximal Plantar Pressures				
Left Foot				
Forefoot (N/cm²)	44.40 (9.80)	45.28 (9.76)	−1.857	0.049
Midfoot (N/cm²)	15.01 (7.54)	15.31 (7.60)	−1.088	0.277
Hindfoot (N/cm²)	33.05 (7.59)	33.69 (7.28)	−0.809	0.419
Right Foot				
Forefoot (N/cm²)	44.55 (10.07)	45.08 (9.91)	−1.900	0.046
Midfoot (N/cm²)	15.03 (6.52)	15.64 (6.62)	−1.855	0.049
Hindfoot (N/cm²)	31.89 (7.07)	32.46 (7.16)	−1.646	0.100

Table 2. *Cont.*

Study Variables	Load Condition		*t*-Value	*p*-Value
	'No Load'	'a 3.5 kg Load'		
Time Maximal Force, % of Stance Time				
Left Foot				
Forefoot (%)	74.44 (2.44)	74.79 (2.13)	−3.101	0.002
Midfoot (%)	41.30 (9.62)	41.02 (9.82)	−2.538	0.011
Hindfoot (%)	18.47 (3.69)	18.88 (3.60)	0.570	0.569
Right Foot				
Forefoot (%)	74.16 (3.48)	74.52 (2.28)	−0.596	0.552
Midfoot (%)	39.70 (9.02)	40.00 (9.10)	−2.303	0.021
Hindfoot (%)	18.06 (3.74)	18.27 (4.05)	−1.102	0.271

Table 3 shows asymmetry characteristics in 'no load' and 'a 3.5 kg load' conditions between the left and right foot. Most notably, 'a 3.5 kg load' significantly increased asymmetries in forefoot (ES = 0.29), midfoot (ES = 0.20) and hindfoot (ES = 0.19) regions of the foot for ground reaction forces. For plantar pressures, only the asymmetry beneath the midfoot region of the foot significantly increased (ES = 0.19). Also, the % of time maximal force during stance time significantly increased beneath the hindfoot (ES = 0.17) region of the foot, while other asymmetries were non-significant.

Table 3. Differences in asymmetries between the left and right foot of the body in 'no load' vs. 'a 3.5 kg load' (mean ± SD).

Study Variables	Asymmetry		Mean Diff.	95% Mean Diff.	*p*-Value
Ground Reaction Forces *	'No Load'	'A 3.5 kg Load'			
Forefoot	0.000 (0.049)	0.014 (0.010)	−0.014	−0.021–0.006	<0.001
Midfoot	0.038 (0.192)	0.076 (0.201)	−0.038	−0.056–−0.019	<0.001
Hindfoot	−0.014 (0.058)	−0.025 (0.058)	0.011	0.005–0.017	<0.001
Plantar Pressures *					
Forefoot	0.001 (0.092)	0.000 (0.089)	0.001	−0.008–0.010	0.779
Midfoot	0.009 (0.171)	0.041 (0.172)	−0.032	−0.049–−0.016	<0.001
Hindfoot	−0.017 (0.085)	−0.019 (0.071)	0.002	−0.005–0.010	0.562
Time Maximal Force, % of Stance Time *					
Forefoot	−0.003 (0.036)	−0.002 (0.017)	−0.001	−0.003–0.002	0.674
Midfoot	−0.018 (0.105)	−0.011 (0.104)	−0.007	−0.017–0.003	0.143
Hindfoot	−0.013 (0.102)	−0.030 (0.101)	0.018	0.008–0.027	<0.001

* All models were adjusted for body mass index.

1. Discussion

This study aimed to investigate the effects of carrying load on ground reaction force and plantar pressure gait asymmetries. The main findings of this study are that (i) 'a 3.5 kg load' significantly increases asymmetries in ground reaction forces, especially in the forefoot and midfoot regions, and (ii) the asymmetry index in plantar pressure also increases, with the largest magnitudes being observed for the forefoot region.

Based on the findings available, this research represents one of the initial examinations of differences in asymmetry under various load conditions among police recruits. As discussed in the Introduction section, previous approaches to defining gait asymmetry between the left and right foot have typically involved measuring ground reaction forces during stance [16,26]. However, there has been limited study on asymmetrical gait analysis during actual gait [12]. Notably, when carrying heavy loads, gait asymmetry in ground reaction forces becomes more pronounced, resulting in differing impacts on the left and right foot. Previous studies have employed asymmetric/unilateral loads to assess the effects of such equipment on kinematic and kinetic gait parameters [12–15,27]. In cases of asymmetric lifting, greater loads are placed on the musculoskeletal system, particularly the trunk, when compared to symmetric lifting techniques [13]. Additionally, the increased asymmetry in ground reaction forces and plantar pressures observed in this study could be attributed to cumulative effects resulting from changes in the inertial patterns of the musculoskeletal system and the restriction of natural arm swing due to load characteristics and lateral trunk position [18]. These findings align with previous research suggesting that deviations in trunk movement away from the loaded side are indicative of motor control actions related to load carriage strategies and characteristics such as weight and shape [12]. Furthermore, it has been observed that compensations between the sides of the body are associated with preferred handedness and alterations in the neuromuscular system. In a study by Alamoudi et al. [27], 20 males carried a load of 10 lbs ($\approx$4.5 kg) in four different modalities of frontal, lateral, bilateral and posterior positions while walking over a Kisler platform (FDM; GmbH, Munich, Germany). Similar to our findings, the compression and shear forces significantly increased with the magnitude of the weight carried, especially in lateral position. This is not surprising, since in our study, a gun with a full handgun's magazine was positioned sideways (left or right side of the body) and might have led to even greater asymmetries. Because of the nature of the load carried, the participants counterbalanced the weight by flexing the trunk, which may have led to an increased distance between the center of mass of the body and weight [28]. Although the latero-flexion of the trunk in the opposite direction prevents from falling and restores body balance, it reduces gait stability [29] and increases gait asymmetry [12]. Also, greater gait asymmetries are often explained by the increased cadence, which occurs to reduce the stress on the joints of the lower limb [30]. Through an exploration of various factors such as load patterns and physiological adaptations [1], policymakers in the healthcare field could potentially revamp existing load structures and adjust their placement on the body. According to a study, the introduction of a '3.5 kg load' was found to have a minor yet noteworthy impact on kinetic gait asymmetry. These alterations were believed to be linked to load placement [31] and increased energy consumption [32].This has been supported previously, where larger individuals classified as 'obese' increase their oxygen and carbon oxide consumption, relative energy expenditure and heart rate [33]. Indeed, obese individuals tend to have higher cardiac stroke volume and a higher mechanical demand on the lungs, which increase inspiratory and expiratory gas volumes and lead to breathing inefficiency [33]. To overcome this problem, we tested the interaction effect of body mass index on gait asymmetries and found non-significant main effects for both men and women, respectively. The cumulative effects of body mass index and 'a 3.5 kg load' carried may not be sufficient to exhibit significant gait changes. First, the participants recruited for this study were a somewhat homogenous group of healthy individuals, with a majority of them being classified as 'normal weight'. Second, a heavier load carried linearly leads to greater gait changes [27] and asymmetries in ground reaction forces and plantar pressures [12], while 'a 3.5 kg load' does not seem to produce such large, but only small effects. Based on the evidence, it is suggested that the safest and most biomechanically appropriate way to carry a load is by using a backpack, keeping the load close to the center of gravity [34]. Although we observed only trivial to small differences between 'no load' vs. 'a 3.5 kg load', there is still an implication of our findings in terms of re-positioning the items of the load. For example, the handgun can be moved to the lateral side of the thigh area to enable the arms to move swiftly during walking. We descriptively observed that the dominant arm often 'freezes' during gait, which increases movements on the opposite side of the body by increasing the lateral flexion of the trunk. In Croatia, the internal policy still dictates that police loads need to be attached around the hips, and future research on this topic are still warranted. Thus, strategies of re-designing police equipment and re-positioning it near the center of body should be implemented within the police system in order to minimize negative effects from the external load on the force and pressure distributions beneath the different foot regions. According to research by Quesada et al. [32], there is a physiological impact of load carriage on the human body. Carrying an additional load equivalent to 15% of the body weight results in a 5–6% increase in metabolic cost. In our own study, we found that a 3.5 kg load, which represents a relative value for our sample, may not significantly increase metabolic cost. However, it can lead to a more pronounced forward lean and distort gait patterns, as indicated by Bobet and Norman [31]. While a 3.5 kg load may not seem substantial enough to induce negative changes in gait, our study revealed that it can lead to increased asymmetries during the gait cycle. Load carriage influences on the anteroposterior and mediolateral planes of the foot, resulting in higher ground reaction forces and plantar pressures, which could lead to discomfort and pain during walking, as noted in previous studies [15,35,36]. Additionally, it may contribute to greater asymmetries between the left and right foot.

Practical implications of our findings can be useful in the field of practice among police officers, because even a small mass of police equipment can lead to a decrease in stability when walking in all planes. On the other hand, in addition to the basic equipment worn by police recruits, the mass of police equipment increases with the difficulty of the task, which can result in even more kinetic asymmetries of gait and increased forces and pressures under certain regions of the feet. One of the mechanisms of prevention of these conditions is the reorganization of police equipment during walking, with the aim of moving the pistol (which is normally carried on the hip) more towards the side of the upper leg, so that the hand on the side of the pistol can have a normal swing while walking. Also, in this way, the position of the torso would move more towards a neutral position (upright stance), which would directly lead to an equal distribution of forces and pressures under the feet on the ground. However, it is important to acknowledge the limitations of our study. The cross-sectional design restricts our ability to establish causal changes in asymmetries and limits the generalizability of our findings to police recruits. Furthermore, our focus on kinetic gait parameters means that we may have missed out on valuable insights provided by 3D kinematic and electromyography systems, which may be served in an inverse dynamic approach for testing torques within each joint. The absence of data pertaining to biological and physiological parameters, injury history and load-carrying techniques further restricts the practical implications of our findings. Finally, the fact that participants walked barefoot over the pressure platform could have impacted the observed gait patterns. Although the nature of the police work strictly dictates wearing appropriate shoes on duty, the methodology of the Zebris platform indicates that all measurements over the platform need to be barefoot-specific, since different types of shoes may mimic true values in ground reaction forces and plantar pressures by absorbing a significant amount of force within the shoe structure. Moving forward, it is essential for subsequent research to adopt a follow-up design and conduct comprehensive physiological and biomechanical analyses. Such studies should also consider load- and injury-related characteristics to mitigate the adverse effects of load carriage on gait.

1. Conclusions

Findings of this study indicate that 'a 3.5 kg load' significantly increases ground reaction force and plantar pressure gait asymmetries beneath the forefoot and midfoot regions, compared to a 'no load' condition. Such asymmetries may have hazardous effects on gait stability and an increased likelihood for musculoskeletal injuries, due to foot pain and discomfort.

These negative changes may impact foot placement on the ground and increase an incidence for future stress fractures and deviated gait biomechanics in police recruits.

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Informed Consent Statement: All subjects gave their informed consent for inclusion before they participated in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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14.3. Study 3

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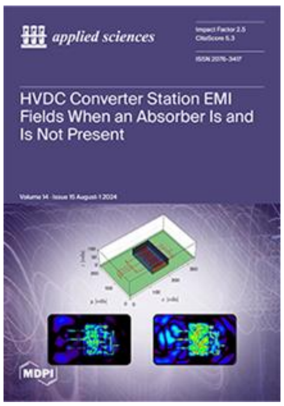

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Load Carriage and Changes in Spatiotemporal and Kinetic Biomechanical Foot Parameters during Quiet Stance in a Large Sample of Police Recruits

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Abstract: Background: Little evidence has been provided regarding the effects of carrying standardized load equipment and foot parameters during quiet standing. Therefore, the main purpose of the study was to examine whether a load carriage might impact static foot parameters in police recruits. Methods: Eight hundred and forty-five police recruits (27.9% women) were tested in 'no load' vs. standardized '3.5 kg load' conditions. Foot characteristics during standing were assessed with the Zebris FDM pedobarographic pressure platform. Results: Carrying a 3.5 kg load significantly increased the 95% confidence ellipse area (Δ = 15.0%, p = 0.009), the center of pressure path length (Δ = 3.3%, p = 0.023) and average velocity (Δ = 11.1%, p = 0.014), the length of the minor axis (Δ = 8.2%, p < 0.009) and the deviation in the X (Δ = 12.4%, p = 0.005) and Y (Δ = 50.0%, p < 0.001) axes. For relative ground reaction forces, a significant increase in the left forefoot (Δ = 2.0%, p = 0.002) and a decrease in the left hindfoot (Δ = −2.0%, p = 0.002) were shown. No significant changes in relative ground reaction forces beneath the forefoot and hindfoot regions for the right foot were observed (p > 0.05). Conclusions: 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

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1. Introduction

Load carriage is an essential part of training and on-duty protocol tasks for special populations, including the military [1,2] and police [3]. Although important, it has been observed that such a load may impact the musculoskeletal system, causing an increased risk of lower limb injury [4] and decreased physical performance [5,6] Moreover, recent studies have observed a negative trend in load weight, often surpassing the recommended level of 45% body mass [7,8]

When carrying heavy loads, gait and posture characteristics often tend to change and adapt [9]. 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 and alternatively causing alternations in body control [10]. The majority of previous evidence has tried to examine the effects of load carriage on foot parameters during gait; however, little evidence has been provided regarding carrying heavy loads and foot stability during a quiet stance [1,11–13]. By carrying a load, a physiological component of increased energy cost and fatigue has often been observed, increasing the risk of injuries and strains [14,15]. For quiet standing, deviations in the center of pressure may be able to predict future risks of injury and postural instability [16], especially in the lower extremities [17]. Both cross-sectional [18] and longitudinal [8,19] studies have shown that different load distributions may have even larger negative effects and can increase the level of asymmetry. Studies conducted during quiet standing have concluded that heavier loads increase the center of pressure velocity and contact area between the foot and the ground, directly affecting ground reaction forces beneath different foot regions [1,20].

The population of police officers needs to be at a high level of preparation [21]. Their primary role includes serving and protecting civilians against crime, and they are engaged in high-risk situations [21]. However, by carrying an uneven load for a long period of time, one could expect significant biomechanical gait changes, especially in a standing position. A unilateral load may affect postural sway, which occurs by shifting the body mass center away from the actual center and leaning forward, producing greater forces beneath the different foot regions [1]. Police recruits encounter carrying a specific external load for the first time, which may have negative effects on their body posture and related biomechanical parameters. Such loads may be responsible for pain and discomfort and a few compensatory mechanisms, especially in the contralateral directions [20]. Since relatively little is known on this topic, it is necessary to examine spatiotemporal foot changes and relative ground reaction forces during quiet standing following a standardized load carriage. By examining such changes, policymakers would be able to act towards re-positioning and re-designing police equipment. The intention behind newly developed equipment would be to increase the possibility of being more efficient in the field during high-risk situations.

Therefore, the main purpose of the study was to examine differences in foot characteristics while standing still under two conditions: (i) 'no load' and (ii) 'a 3.5 kg load'. We hypothesized that heavier loads would exhibit greater biomechanical foot changes and impaired balance compared to the 'no load' condition.

1. Methods

1.1. Study Participants

In this cross-sectional study, we recruited men and women >18 years of age who were part of the one-year academy training program aiming to become a part of the Croatian police service. The training program consists of monitoring and improving health-related physical fitness and learning everyday specific tasks and duties on the field. The technical and tactical parts of the program include handling a gun and behaving in high-risk situations, which are often accompanied by psychological preparation and an assessment of the environment. All these tasks are completed while carrying standardized police equipment on a daily basis. In general, a police academy recruits between 750 and 1000 every year. From December 2023 till the first half of February 2024, when the study was conducted, 900 police recruits were examined and selected to participate in the study. Since the academies' rules and regulations state that all recruits need to be without acute and chronic locomotor or psychological diseases, all eligible participants entered the study at the first stage. Of these, 55 were excluded due to illness or a musculoskeletal injury obtained during the training process. Thus, our final sample included in further analyses was based on 845 police recruits (age mean ± SD = 21.3 ± 2.1 years; height = 176.2 ± 12.6 cm; weight = 74.2 ± 11.8 kg; body mass index = 23.9 ± 3.1 kg/m^2; 27.9% women) (Figure 1). All participants had been given information regarding the general and specific aims, hypotheses, benefits and potential risks. All the procedures were anonymous and in accordance with the Declaration of Helsinki [22]. Furthermore, all participants gave written informed consent to participate in the study. This study was approved by the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1).

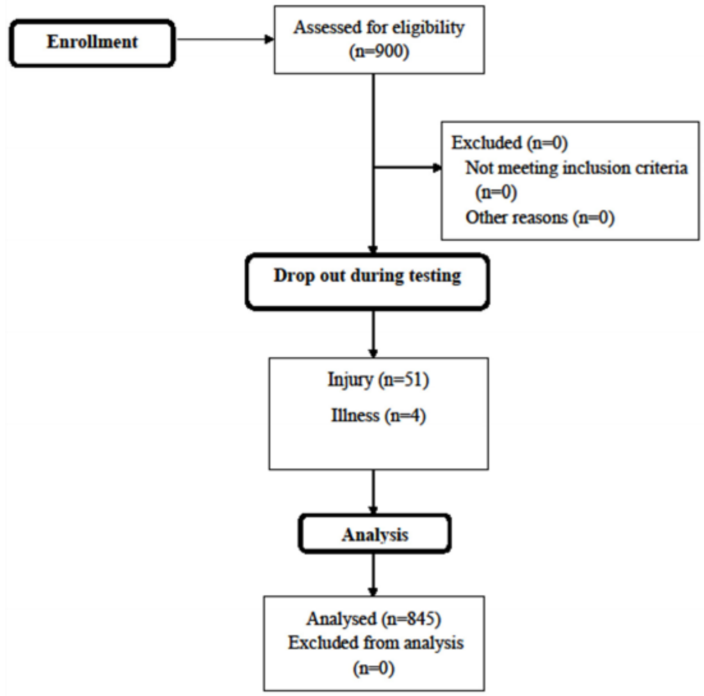

Figure 1. Flow chart diagram of participants' enrolment, randomization and final analysis.

1.1. Load Carriage

A standardized police load often includes a bulletproof vest and a belt, accompanied by a full handgun and an additional handgun magazine consisting of 10 bullets, handcuffs and a nightstick. Based on the nature of this study and the recruitment of future police officers, the training protocol specifically dictates that they only need to have a standardized belt with the aforementioned equipment for physical and mental demands during the day, and the vest is often dismissed due to many task assignments being carried out with the upper body. Although previous evidence has examined the effects of a full load carriage on biomechanical foot parameters [1], for the purpose of this study, we selected standard police equipment carried during police training approximately 10–12 h per day, which consisted of a belt (≈0.5 kg), a gun with a full handgun's magazine (a short barrel HS pistol, ≈1.5 kg), an additional full handgun's magazine (≈0.5 kg), a nightstick (≈0.8 kg) and handcuffs (≈0.2 kg). In total, the whole equipment without a police suit weighs ≈3.5 kg.

1.2. Static Foot Parameters

Measurements of all participants 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 weight. Ground reaction forces (absolute in N and relative in %) were measured. Each participant stepped on the Zebris medical platform for the measurement of pedobarographic plantar characteristics (type FDM 1.5). The Zebris platform uses 11.264 microsensors, 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 still [23]. The Zebris platform was connected via a USB cable to an external unit (laptop). The data were gathered in real time using WinFDM R1.0.0 software for extraction and calculation. Measurement values could be additionally exported in the form of text, pictures, and videos while simultaneously comparing the data from both feet. The capacity of the sensor technology was based on the calibration of every single sensor automatically integrated into the platform. The task was to stand on the platform and maintain a calm position, with arms relaxed by the body and looking straight forward. After 15 s 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 minor axis (X) (mm), (v) length of major axis (Y) (mm), (vi) deviation X, (vii) deviation Y and (viii) the angle between Y and the major axis (°). Specifically, the left and right points under each foot represent the respective area of the CoPs surrounded by the 95% CI. Inside the 95% CI area, the projection of the CoP and its velocity with an appropriate path length during a quiet stance is displayed. The length of the minor axis denotes the medio-lateral direction, while the length of the major axis represents the antero-posterior direction, while the angle between the Y axis and the global y axis is described as the angle between the major axis (Y) and the global y axis, pointing along the longitudinal line of the platform. For ground reaction forces, the software generated the data for the relative forces distributed under the forefoot and backfoot regions of the foot, as well as for the total foot (%). The ideal load distribution is often considered to be 50–50% between the right and left standing surfaces, and the distribution load between the forefoot and heel is suggested to be 33% (1/3) on the forefoot, compared to 66% (2/3) on the heel. Of note, the vertical component of the ground reaction forces was collected and analyzed. Along with biomechanical static foot parameters, in addition, we measured height and weight with standardized equipment (Seca stadiometer and digital scale with a precision of 0.1 cm and 0.1 kg). Height was measured in an upright position while the head was positioned in a neutral position and the vertex was the highest point of the contact. The stadiometer was placed behind the back region from the feet to the vertex, and height was measured in centimeters. To assess weight, each participant stood in a light T-shirt and shorts on the digital scale, which showed each weight in kilograms. Accordingly, body mass index [(weight/kg)/$(\text{height/m})^2$] was calculated to examine nutritional status.

1.1. Statistical Analysis

The Kolmogorov–Smirnov test to examine whether the data were significantly different from the Gauss distribution was used to assess the normality of the distribution. Since all the study variables were not normally distributed, i.e., were significantly different from the normal distribution, the basic descriptive statistics of the study participants were presented as the median with the interquartile range (25th percentile and 75th percentile). Changes in the biomechanical foot parameters during quiet standing with 'no load' vs. 'a 3.5 kg load' were tested using the non-parametric Wilcoxon signed rank test for dependent samples, where differences were examined in one sample during the two measuring conditions: 'no load' vs. a '3.5 kg' load. Cohen D effect sizes of 0.2, 0.5 and 0.8 (small, medium and high) were used to assess the magnitude of differences between 'no load' vs. 'a 3.5 kg load' [24]. Although we tested spatiotemporal and kinetic foot parameters for both men and women, a preliminary analysis showed that there were no significant differences in the changes between them (p = 0.230–0.768), so further analyses were based on the total sample. All statistical analyses were performed using the Statistical Packages for Social Sciences (SPSS. v23.0 software, IBM, Armonk, NY, USA) with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

2. Results

The basic descriptive statistics of the study participants are presented in Table 1. Men were taller, heavier and had higher body mass index values compared to women.

The initial sample of 845 individuals recruited at the beginning met all the inclusion and exclusion criteria. and no individual dropped out of the study during the assessment. In total, further analyses were based on 845 police recruits. The changes in the static foot parameters under the different loading conditions are presented in Table 2. When carrying a '3.5 kg load', the participants exhibited significantly higher values in the confidence ellipse area (mean difference = 19.0 mm^2; ES = 0.33), the center of pressure path length (mean difference = 3.0 mm; ES = 0.11) and average velocity (mean difference =10 mm/s; ES = 0.27), the length of the minor axis (mean difference = 0.7 mm; ES = 0.25), and the deviations in X (mean difference = 1.6 mm; ES = 0.24) and Y (mean difference = 1.8 mm; ES = 0.43). Insignificant spatiotemporal changes in the length of the major axis and the angle between the Y and major axes were observed. For the relative ground reaction forces beneath the different foot regions, carrying a '3.5 kg load' significantly increased the relative average force beneath the left forefoot region (ES = 0.15), while a decrease in the relative average force beneath the left hindfoot was shown (ES = 015). Interestingly, no significant main changes in the right forefoot or hindfoot were observed ($p > 0.05$).

Table 1. Basic descriptive statistics of the study participants.

Study Variables	Total (N = 845)	Men (N = 609)	Women (N = 236)	ES	p-Value
Age (years)	21.3 ± 2.1	21.1 ± 1.9	21.4 ± 2.4	0.02	0.987
Height (centimeters)	176.2 ± 12.6	181.3 ± 10.4	171.9 ± 11.5	0.90	<0.001
Weight (kilograms)	74.2 ± 11.8	82.6 ± 13.4	68.7 ± 10.9	1.04	<0.001
Body mass index (kg/m^2)	23.9 ± 3.1	25.2 ± 3.6	23.2 ± 2.9	0.56	<0.001

Table 2. Basic descriptive statistics and changes in biomechanical static foot parameters under the different loading conditions in police recruits.

Study Variables	'No Load'	'A 3.5-kg Load'	Δ (%)	ES	p-Value
Static Parameters	**Median (25th–75th)**	**Median (25th–75th)**			
Confidence ellipse area (mm^2)	127.0 (76.5–236.0)	146.0 (85.0–253.0)	15.0%	0.33	0.009
Center of pressure path length (mm)	91.0 (64.5–127.0)	94.0 (69.0–134.0)	3.3%	0.11	0.023
Center of pressure average velocity (mm/s)	9.0 (6.0–13.0)	10.0 (7.0–13.0)	11.1%	0.27	0.014
Length of minor axis (mm)	8.5 (6.3–12.0)	9.2 (6.9–12.5)	8.2%	0.25	<0.001
Length of major axis (mm)	19.4 (14.6–27.2)	20.3 (15.2–26.9)	4.6%	0.09	0.201
Angle btw. Y and major axis (°)	77.8 (66.4–84.4)	77.0 (62.8–84.7)	−1.0%	0.02	0.225
Deviation X (mm)	12.9 (4.0–23.5)	14.5 (2.0–26.2)	12.4%	0.24	0.005
Deviation Y (mm)	−3.6 (−9.95–3.10)	−1.8 (−9.7–5.6)	50.0%	0.43	<0.001
Relative average force—left forefoot (%)	51.0 (47.0–55.0)	52.0 (48.0–56.0)	2.0%	0.15	0.002
Relative average force—left hindfoot (%)	49.0 (45.0–53.0)	48.0 (44.0–52.0)	−2.0%	0.15	0.002
Relative average force—left total (%)	47.0 (40.0–53.0)	46.0 (39.0–53.0)	−2.1%	0.10	0.345
Relative average force—right forefoot (%)	50.0 (46.0–54.0)	50.0 (45.0–55.0)	0.0%	0.01	0.714
Relative average force—right hindfoot (%)	50.0 (46.0–54.0)	50.0 (45.0–55.0)	0.0%	0.01	0.578
Relative average force—right total (%)	53.0 (47.0–60.0)	54.0 (47.0–61.0)	1.9%	0.12	0.285

$p < 0.05$.

1. Discussion

The main purpose of the study was to examine changes in foot characteristics during quiet standing under the following two conditions: (i) 'no load' vs. (ii) a '3.5 kg load'. The main findings of the study are as follows: (a) when carrying a '3.5 kg load', significant increases in the confidence ellipse area, the center of pressure path length and average velocity, the length of the minor axis, and the deviation in X and Y are observed and (b) significant changes in the relative ground reaction forces beneath the left forefoot and hindfoot regions are shown.

To the best of the authors' knowledge, this is the first study aiming to investigate the effects of a '3.5 kg load' on spatiotemporal and kinetic foot parameters during quiet standing. Previous evidence has confirmed that heavier loads may impact several foot characteristics during a quiet stance, including increases in the mean postural sway during a double stance, the center of pressure path length, the average velocity and the lengths of the minor and major axes with a decrease in the angle between the Y and major axes [11,20,25]. Evidence suggests that load carriages produce greater foot changes and affect body sway during standing, which directly disrupts the body's center of mass, causing it to shift from a point of stability to the boundaries of the base of support. In that way, one could expect that a loss of balance in the medio-lateral and anterior-posterior directions is essential to maintaining an upright stance by using ankle and hip compensation movements [12,20]. 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 an external load, the resulting body motion is counterbalanced by one of the strategies which increase postural sway. Along with the benefits of carrying a load in high-risk situations, a contra-productive effect on the ability to maintain upright control and posture often occurs. Certain compensations are required to carry an external load in terms of body movement patterns moving away from equilibrium and changing the structure of the postural sway movements [26,27]. Heavy loads have been shown to increase injury incidence and negatively affect physical performance [4]. With increased energy costs and repetitive force requirements, biomechanical changes in spinal loading, gait patterns and ground reaction forces may increase the risk of injuries, with the knees, ankles and feet being the most affected body parts [7,8]. Due to constant load and bone remodeling imbalances, repetitive bone loadings often lead to stress fractures connected to neurological injuries [28]. Indeed, previous evidence suggests that a previous injury is a risk factor for future injury, pointing out that individuals who have experienced a work-related injury are more prone to future injury and ambulatory treatment [29]. Another risk factor for even more foot deviations is load distribution. Although we were unable to test different load distributions and their impacts 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 the contributions of hip muscles to forward progression [30].

This is one of the first studies examining the effects of a '3.5 kg' load on spatiotemporal and kinetic foot parameters during a quiet stance in a large sample of police recruits. Indeed, carrying heavy loads and determining their impact on biomechanical changes during walking [1] and standing [20] have been a topic of interest in the special populations of the military and police, pointing out that a heavy load may have a negative impact on performance and overall body posture during completing everyday tasks and duties. On the other hand, the necessity of carrying equipment represents a crucial component of survival in often high-risk operations and situations. To overcome the reverse health benefits of load carriages, policymakers are keen to develop and implement differently re-positioned and managed loads on the body. For example, studies have shown that when carrying a standardized backpack, it should be placed tightly close to the center of mass to decrease strain in the anterior or lateral positions during walking or standing [5]. Among Croatian police, a handgun is often carried on one side of the hip, which constantly disables the arm of that side of the body from swinging naturally. Although we did not examine the 3D kinematics of the upper body extremities, we observed that the 'affected' arm, both during walking and standing, is positioned further away from the trunk because of the position of the handgun, leading the participants to lean to the other side and have an increased risk of scoliosis and numbness in the neck area and upper extremities. Indeed, previous evidence has shown that a unilateral load carriage is more hazardous to the musculoskeletal body system compared to a bilateral load carriage in terms of increased muscle activity and greater spinal shear [31]. Such a load being carried for a long period of time may impact back curvature positions, leading to scoliotic posture [31]. Biomechanical analyses conducted in individuals carrying a unilateral load have demonstrated that the trunk often bends towards the unloaded side of the body, causing greater hip, knee and ankle joint moments during the single stance phase [32]. Two-way adaptations have been proposed by Huang et al. [33], where the active trunk flexions towards the contralateral side of the body, while the hip adducts greatly lean towards the ipsilateral side of the body. The latter relies on the fact that the trunk is somewhat pulled sideward on the ipsilateral side of the body, while the hip goes in the opposite direction towards the contralateral side. Huang et al. [33] showed that of the two adaptations, the pulling force produced while carrying a unilateral load caused the trunk to bend more to the ipsilateral than the contralateral side of the body. However, the load carried in these studies was much greater (≥10% body weight) compared to the 3.5 kg load (approximately 4% to 5% body weight) used in this study. One potential mechanism of re-positioning the handgun is moving it to the lateral side of the thigh area, which could restrict the arms from moving swiftly and repeatedly. Unfortunately, the policy in Croatia still states that a standardized police load needs to be worn around the hips, and the additional effect of carrying such a load for between 10 and 12 h per day may cause hazardous health-related outcomes in the future. Thus, special interventions and strategies aiming to change the ergonomics and design of police equipment should be implemented within the police system in order to adequately protect one's postural characteristics and utilize energy expenditure during walking and standing [5].

This study has several limitations. First, by using a cross-sectional design, we were unable to examine the longitudinal changes in static foot parameters while carrying heavy loads. Second, we tested healthy men and women between the ages of 18 and 24 who were free of any medical conditions and who could apparently handle body compensations more effectively while carrying equipment compared to more experienced police officers with different socio-demographic backgrounds. Third, we did not collect biological and physiological parameters, which may help to assess the link between static foot parameters and different loading conditions. Also, no data regarding injury history or how the load was carried were collected, limiting the possibility of expanding our findings to practical implications towards re-positioning items and exploring the potential effects of load carriages on the incidence of injuries. Moreover, no 3D kinematic and muscle activation systems were assessed, limiting our findings to be observed only through a pressure platform and a vertical projection of ground reaction forces. Finally, the participants walked barefoot over the pressure platform, potentially limiting the generalizability and applicability of the findings to the different everyday tasks of other populations in police-related fields or military personnel. Based on the aforementioned limitations, future longitudinal studies 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.

1. Conclusions

In summary, this is the first study examining changes in spatiotemporal and kinetic static foot parameters while carrying a '3.5 kg load' vs. 'no load'. The findings of the study showed that an increased external load might increase the confidence ellipse area, the center of pressure path length and average velocity, the length of the minor axis, the deviations in X and Y, and the forefoot and hindfoot regions of the left foot, while the ground reaction forces beneath the right foot regions were not impacted by the load. Therefore, spatial and temporal parameters during quiet standing may be more prone to changes following an external load compared to ground reaction forces, pointing out that future research should focus on foot characteristics rather than forces being generated beneath the feet. The results of this study are important due to the problem of wearing standard police equipment and its influence on spatiotemporal and kinetic parameters during standing. We believe that wearing the same equipment while walking would result in even greater negative biomechanical changes to the feet and thus to the entire body, and future research must concentrate on studying the same effects during standardized tasks and in different physiological states, such as fatigue or sleep deprivation.

Author Contributions: Conceptualization, M.K. and L.Š.; methodology, L.Š.; software, L.Š.; validation, A.Š., M.K. and L.Š.; formal analysis, A.Š. and L.Š.; investigation, M.K.; resources, M.K.; data curation, L.Š.; writing—original draft preparation, A.Š., M.K. and L.Š.; writing—review and editing, A.Š., M.K. and L.Š.; visualization, L.Š.; supervision, M.K.; project administration, M.K.; funding acquisition, M.K. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the Ministry of Internal Affairs and police academy 'Josip Jović' and the Ethical Committee of the Faculty of Kinesiology, University of Zagreb, Croatia (ethical code number: 511-01-128-23-1, date: 3 July 2023).

Informed Consent Statement: All subjects gave their informed consent for inclusion before they participated in the study.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflict of interest.

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15. BIOGRAPHY OF THE AUTHOR AND LIST OF WORKS

Andro Štefan was born on August 31, 1995. in Zagreb, where he successfully completed elementary school (Davorin Trstenjak Elementary School) and high school (XI. Gymnasium). In July 2020, he obtained a master's degree in kinesiology in education and kinesiology recreation at the Faculty of Kinesiology in Zagreb. In 2021, he enrolled in doctoral studies at the Faculty of Kinesiology in Zagreb. From 2020 to 2022, he worked as an external associate at the Faculty of Kinesiology in Zagreb on the subjects Biomechanics, Sports Biomechanics and Gerontokinesiology. He also worked as a teaching assistant for a third-grade student diagnosed with autism and Asperger syndrome, and as a teaching assistant for a seventh-grade student diagnosed with muscular dystrophy. He is the active manager of the "Nordic Walk" program in Maksimir Park, responsible for planning, programming and implementing the Nordic walking training program, as well as one of the managers of the "MAT" program for recreational exercise for the elderly and people with multiple sclerosis in the recreation trade "Biram pokret".

<u>The list of publicly published works is as follows:</u>

1. Kasović, M., Štefan, L., Bilobrk, M., Sladin, D., Štefan, A., Štrbac, I. & Jencikova, K. (2022) The Associations between Plantar Force Distribution and Successfulness in Short-Fire Shooting among Special Police Officers. Applied Sciences, 12 (10), 5199-5199 doi:10.3390/app12105199
2. Kasović, M., Štefan, L. & Štefan, A. (2021) Normative Data for Gait Speed and Height Norm Speed in ≥ 60-Year-Old Men and Women. Clinical Interventions in Aging, Volume 16, 225-230 doi:10.2147/cia. s290071
3. Kasović, M., Štefan, A. & Štefan, L. (2021) The Associations Between Objectively Measured Gait Speed and Subjective Sleep Quality in First-Year University Students, According to Gender. Nature and Science of Sleep, Volume 13, 1663-1668 doi:10.2147/nss. s328218

4. Kasović, M., Kalčik, Z., Štefan, L., Štefan, A. & Knjaz, Damir, Braš, Marijana (2021) Normative Data for Blood Pressure in Croatian War Veterans: A Population-Based Study. International Journal of Environmental Research and Public Health, 18 (8), 1-7.
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