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Effects of Different Load Carriage on Spatiotemporal Gait Parameters in Elite Intervention Police Officers

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Abstract: Carrying heavy loads may present certain biomechanical changes in special populations. However, most of the existing research on whether or not different external loads impact gait biomechanics has been conducted in military personnel, while the same changes have been relatively unknown in other populations, such as police officers. In order to maximize the importance of load ergonomics and design, it is necessary to establish both spatial and temporal gait changes under different load conditions in a variety of high-risk jobs, in order to detect which parameters are the most important for special interventions and policies. Therefore, the purpose of this study was to examine changes in spatial and temporal gait parameters under different loading conditions. Ninety-six intervention police officers were recruited and evaluated. Zebris FDM pedobarographic platform was used to assess spatial and temporal gait changes gradual increases in load carriage significantly increased cadence ($p = 0.024$, $\eta^2 = 0.029$), stance-phase for left ($p = 0.046$, $\eta^2 = 0.024$) and right foot ($p = 0.019$, $\eta^2 = 0.030$), and load response for left ($p = 0.044$, $\eta^2 = 0.025$) and right foot ($p = 0.033$, $\eta^2 = 0.027$), while decreases in step time for left foot ($p = 0.024$, $\eta^2 = 0.029$), and swing phase for left ($p = 0.047$, $\eta^2 = 0.024$) and right foot ($p = 0.047$, $\eta^2 = 0.024$) were observed. No significant changes in spatial gait parameters occurred when carrying heavier loads. In conclusion, increases in external loads lead to larger changes in temporal, but not in spatial foot characteristics during gait. Thus, temporal gait parameters may be more prone to changes when carrying heavy loads.

Keywords: spatiotemporal parameters; gait; intervention police officers; heavy equipment; changes

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1. Introduction

Carrying heavy loads represents a crucial task in a special population of military and police personnel [1–3]. Such loads are often required for protection and providing lifesaving equipment needed for specific operations [1,2]. Although necessary for performing fundamental tasks, evidence suggests that heavy loads often exceed a threshold of 45% of body mass recommended for long distances [4,5]. For the past years, the magnitude of the absolute load being carried has dramatically increased, showing an alarming negative trend that affects energy expenditure costs during walking [6] and increases the risk of musculoskeletal injuries [7].

Carrying an excessive load can also impact the biomechanics of human locomotion [6,8]. During carriage, the extra load requires gait compensations to minimize decrements in maximal performance [8–10]. Most parameters associated with gait include spatiotemporal data, kinematics, ground reaction forces, and electromyography [11]. Among them, previous studies have shown that load carriage significantly impacts gait kinematics, kinetics, and electromyography [11]. In terms of kinematics, evidence suggests that during the loaded conditions, increases in hip [12,13], knee [12,14], neck [15], and trunk [12,15] flexion, ankle dorsiflexion [12] and hip [15,16], knee [15,16] and ankle [12,14,16] range of motion are observed, followed by decreases in trunk sway [17] and trunk range of motion [18]. Compared to unloaded conditions, average and peak plantar pressures [19,20] increase with loaded conditions, along with increased muscle activity [14,17,21,22]. On the other hand, past findings have shown inconclusive results, where the added external mass can impact spatiotemporal gait parameters [6,8] or have no proven effects [11]. For example, previous systematic reviews have shown that external weight may lead to a reduced stride length and an increased cadence during walking [6,8]. However, the most recent systematic review has demonstrated that load carriage had no significant effect on any of the spatiotemporal gait parameters, including walking speed, step or stride length, cadence, step width, and double or single support time [11].

Along with different findings, most of the studies have been conducted among military personnel [11], while the population of different types of police has been less studied. Compared to active-duty soldiers, intervention police officers are often engaged in more vigorous-intensity tasks throughout the day, possibly being at more risk for injuries and sprains [23]. All these activities are accompanied by even heavier load carriage exceeding >50% of body mass on a daily basis, compared to military personnel [23,24]. This would imply that heavier load carriage and the nature of everyday tasks may have different effects on spatiotemporal gait parameters in intervention police officers. Due to these changes, previous findings on military personnel may not be applicable to this population [11].

Therefore, the main purpose of the study was to investigate whether different loading conditions might impact spatiotemporal gait parameters in a representative sample of intervention police officers. Based on one previous study conducted on special police officers [25], which showed non-significant changes in spatiotemporal data under different loading conditions, we hypothesized that heavier loads would lead to statistically unchanged values in both spatial and temporal gait parameters.

2. Materials and Methods

2.1. Study Participants

In this cross-sectional study, we recruited male officers of the Police Intervention Unit of the Zagreb Police Department. By using the G*Power statistical calculator to calculate the sample size and setting a statistical power of 0.80, a p-value of <0.05, and detection of large effect size (0.40), a sufficient number of subjects to participate in the study would be N = 80. Considering the potential dispersion of the sample during the implementation of the study, the sample was increased by 20% (N = 96). To be included in the study, all participants in the research were employees of the Police Intervention Unit for a minimum period of three years. Before and during the test, all participants needed to be without any acute/chronic diseases and injuries that would affect the test results or force them to drop out of the study. The research was conducted anonymously and in accordance with the Helsinki Declaration [26]. Before the study, a written informed consent was signed by all participants. 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).

2.2. Loading Conditions

For each loading condition, participants wore four types of loads proposed by the Ministry of Internal Affairs for intervention police officers: (1) 'no load', which only included their own body weight (2) a 5-kg load referring as 'load 1', which consisted of a belt with a loaded handgun magazine with an additional full handgun magazine and a standard set of handcuffs, (3) a 25-kg load referring as 'load 2', which represented 'load 1' + a helmet, a ballistic vest and a baton, and (4) a 45-kg load referring as 'load 3', which was a cumulative load of 'no load' + 'load 1' + 'load 2' with additional protection equipment for extremities and accompanied by a protective gas mask [25]. Previous findings have suggested that the order of the load being carried should be randomized, for the purpose of reducing a learning effect [25]. It should be noted that each load condition served for specific tasks and duties inside or outside the field for intervention police officers and these loads were chosen due to the highest amount of time being carried during working hours.

2.3. Spatiotemporal Gait Parameters

To be able to calculate spatial and temporal parameters, we used ZEBRIS FDM software (version 1.12), which generated the data after each trial. The software was connected to the pressure platform and installed on the computer, which gave us instant information regarding gait biomechanics. Pre-programmed spatial and temporal gait parameters were generated. For instance, spatial parameters recorded from the software were foot rotation in degrees, step length in cm, stride length in cm, step width in cm, length of gait line from the first to the final contact of the foot with the ground, and a single limb support line in mm. Foot rotation was calculated as the degree between the position of the foot and the line between the feet. Step length denoted the distance between the heel of one foot to the heel of the other foot and stride length summed both steps. Step width was calculated as the parallel distance between the feet. Temporal parameters included step time (in s, stride time in s, cadence as the number of steps per min, and gait speed in m/s). Step time was calculated as the time between the heels of both feet touching the ground and stride time as the summation of left and right step times. In addition, further temporal parameters recoded as % of the gait cycle for both feet were divided into two phases: (i) stance phase described by load response, mid stance, and pre-swing, and (ii) swing phase. Finally, a double stance phase was generated. Of note, foot rotation, step length, length of gait line from the first to the final contact of the foot with the ground, a single support line, step time, and the % of gait cycle were calculated for both left and right foot.

2.4. Testing Procedure

We used a pressure platform (ZEBRIS company, FDM; GmbH, Munich, Germany; number of sensors: 11,264; sampling rate: 100 Hz; sensor area: 149 cm × 54.2 cm) to assess spatiotemporal gait parameters. We followed the testing procedure from previous studies [25], which included walking at a normal pace over the platform back and forth for eight consecutive times. In brief, each participant walked over the pedobarographic platform with an additional 4.5 m custom-designed dense material platform put before and after the testing area. To be able to complete the task, the participants walked a 4.5 m platform after which they stepped and walked over the pressure platform and continued to walk across the next 4.5 m platform to the end of a walkway. When they reached the end, they rotated for 180° and continued to walk over the platform seven more times (eight trials in total). The resting period between each load was approximately 3 min or when the heart rate was below 100 beats per min [16]. As highlighted in the previous section, the equipment being carried by the participants was randomized to reduce the learning effect [25]. In order to establish internal consistency between each trial, we performed the intraclass correlation coefficient for each load condition and showed excellent reliability properties of the pressure platform, ranging from 0.91 to 0.95 for both spatial and temporal gait parameters, indicating no significant deviations or variations between each trial and confirming homogeneity.

2.5. Data Analysis

The Kolmogorov–Smirnov test was used to assess the normality of the distribution. Basic descriptive statistics are presented as mean and standard deviation (SD) for normally distributed variables or as the median and interquartile range (25th–75th) for not normally distributed variables. To examine the differences between the loading conditions, a one-way repeated measures ANOVA or the Friedman test were used. Where significant main effects were observed, a modified Bonferroni *post-hoc* procedure was calculated to observe significant differences between each load condition. Partial eta squared was presented to define 'small' (0.01), 'medium' (0.06), and 'large' (0.14) effect size. Partial eta squared represents a measure of a given association which is often described as the proportion of total variation explained by an independent variable, and variance from other predictor variables from the total non-error variance. All statistical analyses were performed by using SPSS v23.0 software (IBM, Armonk, NY, USA) with an alpha level set a priori at $p < 0.05$ to denote statistical significance.

3. Results

Spatial gait changes under the different loading conditions are presented in Table 1. Carrying heavier loads did not result in significant spatial gait changes ($p > 0.05$). Although non-significant, the largest magnitudes were observed for a single limb support line for both the left and right foot. For the other variables, a gradual increase in stride length, step width, and length of gait line for the left foot was observed, while a non-linear trend in other variables showed that heavier load carriage might not impact spatial gait parameters at the same rate. The spatial parameter to be almost significant was single limb support time for the right foot, where a linear decrease from 'no load' to 'load 3' was observed; however, differences remained statistically non-significant.

Table 1. Changes in spatial gait parameters under the different loading conditions.

Study Variables	**'No Load'**	**'Load 1'**	**'Load 2'**	**'Load 3'**	**Main Effect**	
Spatial Gait Parameters	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	***F* (*p*-Value)**	**η^2**
Foot rotation-L (°) *	8.3 (4.9–11.4)	7.8 (4.9–11.4)	8.6 (5.2–11.6)	8.1 (5.3–10.7)	0.509 (0.667)	0.005
Foot rotation-R (°) *	10.1 (7.4–14.7)	9.9 (6.1–14.4)	10.3 (7.7–14.0)	9.9 (6.7–13.9)	0.094 (0.963)	0.001
Step length-L (cm)	68.5 (5.6)	68.7 (6.3)	68.5 (6.3)	68.9 (6.4)	0.086 (0.968)	0.001
Step length-R (cm)	67.6 (5.9)	68.7 (5.8)	68.5 (6.0)	69.0 (6.2)	0.901 (0.441)	0.008
Stride length (cm)	136.0 (10.6)	136.8 (11.0)	137.0 (11.7)	137.9 (12.0)	0.385 (0.764)	0.004
Step width (cm)	15.3 (2.9)	15.4 (2.7)	15.6 (2.8)	15.7 (2.9)	0.311 (0.817)	0.002
Length of gait line-L (mm)	239.1 (26.3)	242.4 (22.1)	245.1 (17.9)	242.7 (22.9)	1.118 (0.342)	0.009
Length of gait line-R (mm)	242.4 (18.2)	239.5 (23.6)	240.9 (24.9)	243.3 (19.4)	0.587 (0.624)	0.005
Single limb support line-L (mm)	121.6 (21.3)	127.1 (20.4)	124.8 (13.9)	123.5 (13.8)	1.382 (0.248)	0.013
Single limb support line-R (mm)	125.7 (13.0)	122.0 (15.4)	120.6 (17.2)	120.7 (14.6)	2.060 (0.105)	0.019

* denotes using median and interquartile range (25th–75th percentile); $p < 0.05$.

Table 2 shows temporal gait changes under the different loading conditions. Significant decrements of values after applying heavier loads were observed for 'step- time-L', 'swing phase-L', and swing phase-R'. Specifically, significant differences were shown between the 'no load' and 'load 3' conditions for all variables. On the other hand, significant increments in values for 'cadence', 'stance phase-L', 'stance phase-R', 'load response-L', and 'load response-R' were observed. A *post-hoc* analysis showed that significant differences occurred between 'no load' and 'load 3' for 'cadence' (mean diff. −3.807, 95% CI −7.114–−0.500, $p = 0.015$), between 'load 1' and 'load 3' for 'stance phase-R' (mean diff. −0.981, 95% CI −1.897–−0.064, $p = 0.029$) and between 'load 1' and 'load 3' for 'load response-R' (mean diff. −0.751, 95% CI −1.468–−0.034, $p = 0.034$). No significant differences in other temporal gait parameters were detected ($p > 0.05$). Although significant temporal changes occurred, partial eta squared showed only trivial to small effect sizes between the load conditions, with the highest being obtained for the stance phase for the right foot and the lowest for the swing phase for both the left and right foot.

Table 2. Changes in temporal gait parameters under the different loading conditions.

Study Variables	'No Load'	'Load 1'	'Load 2'	'Load 3'	Main Effect	
Temporal Gait Parameters	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	***F* (*p*-Value)**	**η^2**
Step time-L (s)	0.55 (0.04)	0.54 (0.04)	0.54 (0.04)	0.53 (0.04)	**3.073 (0.028)**	**0.028**
Step time-R (s)	0.55 (0.04)	0.55 (0.06)	0.55 (0.05)	0.54 (0.04)	1.702 (0.167)	0.016
Stride time (s)	1.11 (0.08)	1.09 (0.09)	1.09 (0.09)	1.07 (0.08)	2.431 (0.065)	0.022
Cadence (steps/min)	108.6 (7.7)	110.8 (7.8)	111.1 (8.4)	112.4 (8.1)	**3.191 (0.024)**	**0.029**
Gait speed (m/s)	4.44 (0.48)	4.57 (0.53)	4.59 (0.57)	4.66 (0.58)	2.423 (0.066)	0.022
Stance phase-L (%)	62.1 (2.1)	62.3 (1.9)	62.7 (1.8)	62.8 (1.9)	**2.694 (0.046)**	**0.024**
Stance phase-R (%)	62.3 (1.7)	61.6 (3.1)	62.5 (1.9)	62.5 (1.9)	**3.378 (0.019)**	**0.030**
Load response-L (%)	12.3 (1.5)	11.8 (1.6)	12.4 (1.9)	12.6 (1.5)	**2.729 (0.044)**	**0.025**
Load response-R (%)	12.0 (1.9)	12.1 (1.5)	12.7 (2.0)	12.7 (2.2)	**2.943 (0.033)**	**0.027**
Mid stance-L (%)	37.8 (1.7)	38.4 (3.0)	37.7 (2.3)	37.5 (2.1)	1.827 (0.142)	0.017
Mid stance-R (%)	37.5 (3.9)	37.5 (2.0)	37.2 (2.0)	37.2 (2.0)	0.311 (0.817)	0.003
Pre-swing-L (%)	12.1 (1.9)	12.3 (1.6)	12.5 (2.0)	12.7 (2.1)	1.686 (0.170)	0.015
Pre-swing-R (%)	12.3 (1.5)	12.2 (2.0)	12.9 (1.8)	12.7 (1.4)	**2.909 (0.035)**	**0.026**
Swing phase-L (%)	37.9 (2.1)	37.6 (1.5)	37.3 (1.8)	37.2 (1.9)	**2.688 (0.047)**	**0.024**
Swing phase-R (%)	37.7 (1.7)	38.3 (2.9)	37.5 (1.9)	375 (1.9)	**2.681 (0.047)**	**0.024**
Double stance phase (%)	24.8 (4.6)	24.3 (2.7)	25.4 (2.8)	255 (3.0)	2.132 (0.096)	0.019

$p < 0.05$.

4. Discussion

The main purpose of the study was to investigate whether different loading conditions might impact spatiotemporal gait parameters in a representative sample of intervention police officers. The main findings of the study are: (i) no significant changes in spatial gait parameters occur when carrying heavier loads, and (ii) heavier load carriage resulted in significant temporal increases for 'cadence', 'stance-phase-L', stance-phase-R', 'load response-L', and 'load response-R' and in decreases for 'step time-L', 'swing phase-L', and 'swing phase-R'.

Findings that carrying heavy loads led to non-significant spatial gait changes are in line with previous findings [13,20,25,27,28]. Specifically, a study by Schulze et al. [13] conducted among 32 male active soldiers accompanied with five loading conditions performed on a treadmill showed non-significant effects of heavier loads on stride length. Similar findings have been reported in a study by Park et al. [20], where the external load gradually increases from 'no load' to a '27-kg load' with no marked effects on step length, step width, and gait velocity. Another two studies also showed that the additional mass had no effect on spatial gait parameters [25,27,28]. In line with that, a recent systematic review has shown that load carriage has no proven effects on spatial gait parameters [11]. Despite mass differences between load equipment, non-significant changes in spatial gait parameters may be due to evenly distributed loads on the body, causing somewhat symmetrical gait movements without deviations or compensations [11]. However, two previous systematic reviews of Boffey et al. [6] and Liew et al. [8] have found altered spatial gait parameters when carrying heavy loads. It should be noted, that of three systematic reviews [6,8,11], two of them included a mixture of military, civilian, and unknown populations [6,8], while the last one was conducted in military personnel [11]. The discrepancy between the findings may be related to a different response to heavy loads between military and civilian/unknown populations, where active soldiers are less affected by loads [11]. Also, different testing conditions in terms of self-paced vs. pre-determined walking speed may have resulted in different energy costs and fatigue development during task performance. This would suggest that spatial gait parameters are uninterrupted by carrying heavier loads due to their robustness to external mass [11].

We found that heavier loads carried by intervention police decreased the step time of the left foot, swing phase of both feet and increased cadence, stance phase, and load response of both feet, which is not in line with previous studies [12,13,17,20,25,28]. Specifically, evidence suggests non-existing effects between carrying heavy loads and temporal gait parameters, such as gait speed [12,20,25], cadence [12,28], or double and single support time [12], even after applying different loading strategies of backpack/backpack and armor loads [12,13,17], 8 kg webbing [28], vest or body armor loads [20,28] and a rifle [12,13,17]. Although the majority of the studies found no significant effects of heavy loads on temporal parameters [12,13,17,20,25,28], some studies have demonstrated an increase in stance phase and double support time with external loads [20], an increase in cadence and double support time when walking uphill or downhill [29] and an increase in mid stance time [12]. These increases in different gait phases are often explained by generating greater vertical and horizontal ground impulses to overcome the added inertial of the external load [11]. It should be highlighted that the participants in studies reporting increases in different gait phases have been instructed to walk at self-selected speeds [12,20], as opposed to treadmill walking [13,17] or running [28]. When walking speeds are self-regulated, it is possible that the time spent in different gait phases is altered and, therefore, increased to accommodate the load, while similar scenarios on a treadmill with pre-determined gait speed may alternatively mask these changes [11].

Although this study showed significant temporal, but not spatial, changes in gait parameters following heavier load carriage, the perspective of our findings is multifactorial. Based on the results, no significant spatial gait changes occurred even after carrying approximately 50% body mass, indicating that intervention police officers have developed a neuro-muscular adaptation to external heavy load after years of experience and being under constant stressful events and tasks. On the other hand, some of the temporal gait parameters significantly changed, especially in terms of cadence, pre-swing and swing gait cycles. This would imply that a single-legged part of gait under different load conditions may be more prone to changes than other temporal parameters. However, the inability to measure and track intervention police officers prior to entering the service and establish their biomechanical gait characteristics disabled us from comparing and testing the effects of standardized equipment being carried. However, from a practical point of view, we only observed very low partial eta squared, meaning that although significant temporal changes occurred, clinical implications of our data might be not relevant for taking an extra step forward for changing and re-positioning heavy equipment in intervention police officers. Unfortunately, we were unable to test the impact of previous experience of carrying heavy loads; therefore, the findings of this study should be interpreted with caution. Along with this limitation, our study has several limitations. We did not measure gait kinematics or muscle activity properties during walking. Second, a self-selected walking speed can be a compensatory mechanism for altering gait locomotion to accommodate external heavy loads. By using a pre-determined treadmill walking speed, we might have observed different gait changes. Third, the load was not tested independently of how it was distributed on the body. Fourth, the testing procedure was based on walking barefoot, which is not a common practice during specific task performances. By using in-shoe insoles, we would be able to examine the effects in real situations, compared to laboratory testing. In addition to several limitations, this study has strengths. First, we used a relatively new technology to examine spatial and temporal changes in gait biomechanics in intervention police officers, following different load conditions. For instance, the majority of previous studies have conducted their research on military personnel [11], limiting the generalizability of the findings to other special populations. Next, a standardized load equipment was used to determine whether such external load might impact walking characteristics. Finally, compared to previous evidence [11], a relatively large sample was recruited, which gave us the opportunity to test gait differences without the loss of statistical power. Although this study is one of the first to examine changes in spatial and temporal gait parameters in intervention police officers, based on study limitations, future research should be based on investigating these changes in different special populations (police, military, firefighters) and by including kinematics, kinetics, and electromyography properties of the gait under different load conditions, in order to establish global differences and detect these parameters that discriminated between the groups.

5. Conclusions

In summary, this study shows that carrying heavy loads does not seem to impact spatial gait parameters, but leads to significant changes in some temporal gait parameters, including shorter step time and swing phase, and longer cadence, stance phase, and load response of the gait. The findings would suggest that temporal gait parameters may be more prone to changes under different loading conditions in intervention police officers, compared to spatial gait parameters. Although we observed significant temporal gait changes, trivial to small effect sizes occurred, pointing out that these changes may not be important for clinical practice or even re-distributing the load differently on the body for better ergonomics during walking. However, from a public health perspective, cumulative load carriage during a long period of time may be responsible for higher injury risk and distribution compensations in intervention police officers, showing that policymakers should pay more attention to equipment and the way of carrying it on a daily basis.

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Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to the privacy.

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