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# Effects of Treadmill Inclination and Load Position on Gait Parameters while Carrying a Backpack Asymmetrically

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**Abstract:** Incline walking with an external load is a common activity in everyday life. Asymmetrical load carriage can lead to abnormal posture and back pain. Thus, this study aimed to examine the effect of walking uphill with an asymmetrical load in two positions on the spatiotemporal parameters of gait in young adults. Forty-one asymptomatic human volunteers were enrolled in this study. They were asked to walk at a self-selected pace on level and uphill (+5° incline) surfaces carrying a backpack in two asymmetrical positions (hand and shoulder). Spatiotemporal gait parameters were recorded using a photocell device. We observed a significant effect of incline and load position on gait parameters ($p < 0.05$). Although adaptation to walking on inclines was similar with and without a backpack, adaptation to load position was different when the load was hand-held and shoulder-held. Asymmetric loading with different load locations should be considered an important factor influencing daily gait patterns. In the future, this relationship should be further investigated in terms of pain disorders and postural abnormalities.

**Keywords:** gait cycle; asymmetric load; surface inclination; step length



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## 1. Introduction

Sloping gait is one of the fundamental skills [1]. Incline walking is a common form of physical activity that can be incorporated into everyday routines, such as transportation and recreation. In many cases, it is part of normal activities, e.g., for hilly area residents, or professional activities, e.g., for rescue team members [2,3]. However, uphill walking can be demanding for muscles, joints and postural stability, leading to certain adaptations of movement patterns [4–6]. Postural stability was strongly affected by the level in the anterior–posterior direction even when the inclination was small (5°) [4]. Also, a correlation between the stability parameters and the joint reaction force was found [5]. Kimel-Naor et al. reported that step length, stride length, gait speed and cadence were significantly smaller in the uphill walking condition as compared to level walking [6].

People frequently carry loads using backpacks with shoulder straps. Carrying a backpack using a single strap is very common and popular especially among young people, e.g., students, leading to a continuous asymmetrical loading of the body. This negative effect is more dangerous because it can last from school age to adulthood, a period during which body posture undergoes dynamic development [7,8]. Walking while carrying an uneven load can lead to a shorter stride length, faster cadence and decreased gait stability compared to walking without a load [9–11]. Zwick et al. reported that subjects carrying loads by their sides may increase their cadence and decrease their stride length in order to maintain velocity and reduce stress. In their study, Alamoudi et al. observed that there was no significant alteration in stride length and cadence during load carriage. However, they noted a significant mediolateral deviation of the center of mass when the load was carried laterally compared to bilaterally and during normal walking [9]. Wang et al. suggest that asymmetrical loading can also lead to abnormal limb coordination during gait cycle [10]. The literature also indicates that carrying a backpack is linked to an increased trunk flexion angle, as well as an increased hip and ankle range of motion during the gait cycle [12]. Several variations in backpack carriage protocols may contribute to differences in study results, including walking speed and load position [12,13].

The adjustments in trunk muscle activities and lumbar posture induced by carrying a backpack are indicative of alterations in the active and passive response of the lower back tissues. This, in turn, affects spinal load, which represents a significant causative factor for low back pain (LBP) [14]. Previous studies reported that an increased backpack weight is associated with an increased prevalence of annual LBP [15]. Thus, wearing a backpack heavier than 10% of one's body weight is not recommended for school children [16]. Carrying an excessive load in an asymmetric position, such as using a backpack in a unilateral position, contributes to poor walking posture [17], which can lead to gait alterations, e.g., decreased gait stability and regularity [18]. Previous studies suggest that there is a relationship between altered movement patterns and LBP [19]. However, an interaction effect between load position and incline walking on gait patterns has not yet been well established. Although the influence of weight position on posture and gait has been widely studied, it is still unclear whether there are differences between the loaded and unloaded sides during walking with asymmetrical load carriage. The impact of wearing a backpack with an additional load, and the placement of the load, on gait features such as stability is a critical area of focus. Adapting gait patterns to external factors may explain the mechanisms of LBP, maintaining balance and preventing falls. Exploring the alterations in gait patterns due to changes in weight distribution and variations in surface inclination will significantly enhance our understanding of gait mechanics under asymmetrical loading conditions.

The aim of this study was to examine the effect of walking uphill with asymmetrical loads in two positions (hand and shoulder) on the spatiotemporal parameters of gait in young adults. Moreover, we additionally investigated the effect of the side (loaded and unloaded). We hypothesized that the incline, position and side of the load would significantly affect the duration of single and double support phases, as well as cadence and step length during a steady pace.

## 2. Materials and Methods

### *2.1. Participants*

Forty-one young adults from the student population were recruited for this study. This group was selected due to their particular exposure to the asymmetrical load associated with carrying backpacks to classes. The exclusion criteria from the study were age <18 years or >30 years (to avoid the influence of age on gait parameters), lack of consent to participate in the study or withdrawal from the study, pain in the musculoskeletal system, balance disorders and trauma to the musculoskeletal system in the last 6 months. The inclusion criteria were age between 18 and 30 years, written consent to participate in the study, lack of musculoskeletal pain or injuries in the last 6 months and lack of reported balance disorders.

The research protocol received a positive response from the Bioethics Committee No. KE-0254/22/01/2024. Prior to data collection, informed consent was obtained from the participants. The research was conducted from January to April 2024. The place where the research was carried out was the biomechanics laboratory.

### *2.2. Instrumentation and Testing Procedures*

The measurement tool was OptoGait (Microgate, Bolzano, Italy) [20]. The photoelectric cell system was used for biomechanical analysis of movement, including step length, contact time and frequency. The device consists of two bars (transmitting and receiving) emitting light using Light Emitting Diodes (LED)and a computer with software (OptoGait Software Version 1.13.4). The system records the time and area of interruption of contact between the strips, which allows the estimation of spatiotemporal parameters. The bars are placed on the sides of the Monark medical treadmill (Monark, Sweden) at the same level as the contact surfaces [21]. The validity of the OptoGait system for the evaluation of spatiotemporal gait parameters in healthy adults was demonstrated in a previous study [20]. All parameters were measured bilaterally.

Before testing, participants completed the short version of the International Physical Activity Questionnaire (IPAQ) [22]. The IPAQ consists of questions about the amount of walking, participation in moderate and vigorous activities and sitting time. The questionnaire describes physical activity in METmin/week (Metabolic Equivalent of Task). This unit is used to estimate the metabolic cost of physical activity (PA) (energy expenditure as reflected by oxygen consumption) [23].

Participants held a backpack on their shoulder or in their hand while walking on a treadmill. We selected these loading positions due to their varying distances from the global center of mass. We decided to focus on those two positions because adding more positions can elongate walking time and result in fatigue, which can influence results. The backpack's weight was calculated as 10% of the body weight, and for loading, dumbbells were used. The backpack's position was adjusted by tightening the straps so that the lower edge of the backpack was at the level of the upper part of the sacrum [24] (Figure 1).

(**a**) (**b**)

**Figure 1.** (**a**) Backpack with marked dimensions. Height, 38 cm (green line); width, 28 cm (red line); depth, 15 cm (yellow line). (**b**) Adjusting the backpack position to the participant so that the lower edge of the backpack was at the level of the upper part of the sacrum and the backpack fitted tightly to the back.

The examined person wore sports clothes and was without shoes [25,26] during gait measurements on the treadmill. Barefoot walking eliminates discrepancies related to different types of footwear and does not require any standardization of shoe parameters. The participant first walked on the treadmill for approximately 5 min to warm up, selecting their preferred comfortable speed for normal walking [21]. Then, they walked for approximately 1 min during each trial to familiarize themselves with the conditions, of which 30 s was recorded [27]. Order of trails: (1) control trial—unloaded walking at preferred speed (no treadmill incline and with +5° incline); (2) backpack walking at preferred speed without treadmill incline (backpack on shoulder, backpack in hand); (3) backpack walking at preferred speed with +5° incline (backpack on shoulder, backpack in hand). There was one trial for each condition, with continuous recording of gait parameters for 30 s. Participants carried the backpack on their preferred side, which was established based on questions about their preference for carrying bags/backpacks during their daily activities (Figure 2).


(**a**) (**b**)

**Figure 2.** Participant while walking on a treadmill: (**a**) carrying a backpack on the shoulder; (**b**) carrying a backpack in the hand.

### *2.3. Data Analysis*

Definitions of the spatiotemporal parameters analyzed in the current study:

- Normalized Step Length [%] [28]:

$$\text{Normalized Step Length} = [\text{Step length (cm)}/\text{Body height (cm)}] \times 100\%; \quad (1)$$

- Step length [cm]: The distance between the point of heel contact of one foot and the point of a successive heel contact of the contralateral foot [2];
- Stance phase [% of gait cycle]: the heel-to-toe contact sequence of the foot [2];
- Swing phase [% of gait cycle]: the foot is suspended and proceeds in the air [2];
- Double support [% of gait cycle]: period of time when both feet touch the ground [2];
- Single support [% of gait cycle]: the time during which the entire plantar aspect of the weight-bearing foot has contact with the ground [2];
- Cadence [steps/min]: rhythm expressed in steps per minute [2];
- Gait cycle [s]: time between the first contact of two consecutive steps of the same foot [2].

### *2.4. Statistical Analysis*

For participants' characteristics (age, body mass, height, Body Mass Index (BMI), PA, preferred gait speed), a Mann–Whitney test was used due to non-normal data distribution. Spatiotemporal variables of gait exhibited a normal distribution (Shapiro–Wilk test, $p > 0.05$). Multivariate analysis of variance (MANOVA) with repeated measures was performed on the parameters of gait pattern. Provided that the MANOVA was significant, a univariate one-way ANOVA was performed on each dependent variable to determine those affected by factors. To assess the effects of the inclination and load positions, a repeated-measures ANOVA considering incline (2 levels, 0° and +5° incline), positioning (3 levels, hand, shoulder, no-load) and side (2 levels, unloaded (unpreferred side) and loaded (preferred side)) as factors was performed, followed by a post hoc test using a Bonferroni correction. A Mauchly test was used to check the assumption of sphericity, and Greenhouse–Geisser correction was used to adjust for a lack of sphericity where needed. The ANOVA effect size was expressed by its ${\eta_p}^2$; 0.01 was interpreted as a small effect size, 0.06 was indicative of a medium effect size and 0.14 was indicative of a large effect size [29]. Statistical analysis was performed using STATISTICA computer software (v. 14.0.0.15, TIBCO Software Inc., Palo Alto, CA, USA; 2020), with the significance level set to $p < 0.05$.

The minimum sample size required to detect a statistically significant effect was determined using G*Power software (v.3.1.9.7, Germany) [18]. This calculation was based on the *F*-test, MANOVA, with repeated measures, within the following factors and input parameters: an alpha level of 0.05, a statistical power of 0.80, an ${\eta_p}^2$ value of 0.06 (medium effect size f = 0.25) and a number of repeated measures equal to 12 (2 × 3 × 2). The analysis indicated a necessary sample size of 33. With 41 participants, the present study exceeded this minimum requirement.

## 3. Results

Forty-one participants aged 18–26 were examined (females: $n = 22$; males: $n = 19$). There was a statistically significant difference in body mass, height and body mass index (BMI) between males and females. BMI in men was higher than in women (25.41 vs. 21.72, $p < 0.001$). There were no statistically significant differences in the level of PA between women and men in any aspect of activity. There were also no significant differences between women and men in sitting time and preferred walking speed. Both women and men more often declared that they carried a load in their right hand/on the right shoulder (75.61%). Detailed results are presented in Table 1.

**Table 1.** Comparison of males and females in terms of age, height, weight, Body Mass Index (BMI) and physical activity (PA).

| Variable | Males | | Females | | Statistics | |
|---|---|---|---|---|---|---|
| | ***M*** | ***SD*** | ***M*** | ***SD*** | ***Z*** | ***p*** |
| Age [years] | 22.58 | 1.46 | 22.50 | 1.50 | 0.29 | 0.77 |
| Height [m] | 1.77 | 0.08 | 1.70 | 0.05 | 3.29 | 0.001 * |
| Body mass [kg] | 80.26 | 14.23 | 62.55 | 12.73 | 3.69 | <0.001 * |
| BMI [kg/m$^2$] | 25.41 | 3.53 | 21.72 | 4.89 | 3.02 | <0.001 * |
| Intensive PA [METmin/week] | 884.44 | 1042.88 | 308.57 | 526.60 | 1.76 | 0.08 |
| Moderate PA [METmin/week] | 644.44 | 625.10 | 907.81 | 1372.30 | 0.06 | 0.95 |
| Walking [METmin/week] | 1445.92 | 1548.41 | 1132.21 | 1123.07 | 0.89 | 0.37 |
| Sitting [min/day] | 285.56 | 137.98 | 293.50 | 140.46 | −0.38 | 0.70 |
| Preferred gait speed [km/h] | 3.78 | 0.79 | 3.35 | 0.89 | 1.38 | 0.17 |

* Statistically significant difference ($p < 0.05$).

The MANOVA analysis revealed significant overall effects of incline and load position and interactions of those factors (Table 2). This significant result permitted additional univariate analysis to identify the significant dependent variables. There was no statistically significant difference between the loaded and unloaded sides.

**Table 2.** Multivariate analysis of variance (MANOVA) results for gait parameters. Multivariate tests of significance.

| Main Effect | Test | λ Value | F | Effect df | *p* |
|---|---|---|---|---|---|
| Incline | Wilks | 0.15 | 27.43 | 7 | <0.001 * |
| Load position | Wilks | 0.16 | 10.27 | 14 | <0.001 * |
| Side | Wilks | 0.77 | 1.46 | 7 | 0.21 |
| Interaction | | | | | |
| Incline × oad | Wilks | 0.33 | 3.93 | 14 | 0.001 * |
| Incline × Side | Wilks | 0.82 | 1.09 | 7 | 0.39 |
| Load × Side | Wilks | 0.58 | 1.43 | 14 | 0.21 |
| Incline × Load × Side | Wilks | 0.56 | 1.54 | 14 | 0.16 |

* Statistically significant difference ($p < 0.05$).

### 3.1. Incline Effect

The subsequent univariate ANOVA demonstrated a significant incline effect in all parameters: normalized step length ($F = 7.53$, $p = 0.009$, $\eta_p{}^2 = 0.16$), stance phase ($F = 111.60$, $p < 0.001$, $\eta_p{}^2 = 0.74$), swing phase ($F = 111.35$, $p < 0.001$, $\eta_p{}^2 = 0.74$), single support ($F = 168.61$, $p < 0.001$, $\eta_p{}^2 = 0.81$), double support ($F = 152.72$, $p < 0.001$, $\eta_p{}^2 = 0.79$), gait cycle ($F = 19.42$, $p < 0.001$, $\eta_p{}^2 = 0.32$) and cadence ($F = 21.04$, $p < 0.001$, $\eta_p{}^2 = 0.34$).

During uphill walking, participants increased their step length ($p = 0.009$), stance phase ($p < 0.001$), double support ($p < 0.001$) and gait cycle time ($p < 0.001$) compared to level walking. Simultaneously, a decrease was observed in the swing phase ($p < 0.001$), single support ($p < 0.001$) and cadence ($p < 0.001$) while uphill walking compared to level walking with the same treadmill pace. Tables 3 and 4 show detailed results, including means and the 95% confidence interval (CI) of gait parameters during level and incline walking.

**Table 3.** Mean (M) and 95% confidence intervals (CI) for gait parameters while walking on a level surface.

| Parameter | Backpack in Hand | Backpack on Shoulder | Without Backpack (Control Trial) |
|---|---|---|---|
| | Mean (95% CI) | Mean (95% CI) | Mean (95% CI) |
| **Norm. Step Length [%]** | | | |
| Unloaded Side | 30.68 (29.13, 32.23) | 31.17 (29.58, 32.76) | 31.20 (29.66, 32.73) |
| Loaded Side | 30.80 (29.24, 32.37) | 31.46 (29.86, 33.07) | 31.29 (29.62, 32.97) |
| **Stance Phase [%]** | | | |
| Unloaded Side | 67.81 (67.04, 68.58) | 68.57 (67.79, 69.35) | 67.40 (66.55, 68.25) |
| Loaded Side | 67.92 (67.13, 68.71) | 68.41 67.58, 69.23 | 67.46 (66.64, 68.28) |
| **Swing Phase [%]** | | | |
| Unloaded Side | 32.18 (31.39, 32.96) | 31.43 (30.65, 32.22) | 32.60 (31.75, 33.45) |
| Loaded Side | 32.08 (31.29, 32.87) | 31.59 (30.77, 32.42) | 32.54 (31.72, 33.36) |

**Table 3.** *Cont.*

| Parameter | Backpack in Hand | Backpack on Shoulder | Without Backpack (Control Trial) |
|---|---|---|---|
| | **Mean (95% CI)** | **Mean (95% CI)** | **Mean (95% CI)** |
| **Single Support [%]** | | | |
| Unloaded Side | 31.89 (31.05, 32.73) | 31.70 (30.87, 32.52) | 32.56 (31.73, 33.38) |
| Loaded Side | 32.28 (31.52, 33.03) | 31.80 (30.97, 32.63) | 32.60 (31.75, 33.45) |
| **Double Support [%]** | | | |
| Unloaded Side | 35.96 (34.38, 37.53) | 36.88 (35.31, 38.44) | 34.85 (33.21, 36.49) |
| Loaded Side | 35.65 (34.16, 37.14) | 36.62 (35.02, 38.22) | 34.87 (33.24, 36.50) |
| **Gait Cycle [s]** | | | |
| Unloaded Side | 1.10 (1.05, 1.14) | 1.12 (1.08, 1.16) | 1.12 (1.08, 1.16) |
| Loaded Side | 1.09 (1.05, 1.13) | 1.12 (1.08, 1.16) | 1.12 (1.08, 1.16) |
| **Cadence [step/min]** | | | |
| Unloaded Side | 111.16 (107.04, 115.28) | 108.69 (104.85, 112.52) | 108.35 (104.64, 112.05) |
| Loaded Side | 111.05 (107.19, 114.92) | 108.64 (104.87, 112.41) | 108.36 (104.66, 112.06) |

**Table 4.** Mean and 95% confidence intervals (CI) for gait parameters during walking uphill (+5° treadmill incline).

| Parameter | Backpack in Hand | Backpack on Shoulder | Without Backpack (Control Trial) |
|---|---|---|---|
| | **Mean (95% CI)** | **Mean (95% CI)** | **Mean (95% CI)** |
| **Norm. Step Length [%]** | | | |
| Unloaded Side | 31.24 (29.73, 32.76) | 31.39 (29.86, 32.92) | 31.46 (29.90, 33.03) |
| Loaded Side | 31.29 (29.65, 32.93) | 31.49 (29.91, 33.07) | 31.66 (30.05, 33.27) |
| **Stance Phase [%]** | | | |
| Unloaded Side | 69.86 (69.15, 70.58) | 70.15 (69.44, 70.86) | 68.63 (67.84, 69.42) |
| Loaded Side | 69.85 (69.13, 70.57) | 69.97 (69.23, 70.71) | 68.83 (68.10, 69.56) |
| **Swing Phase [%]** | | | |
| Unloaded Side | 30.14 (29.42, 30.86) | 29.85 (29.14, 30.56) | 31.37 (30.58, 32.16) |
| Loaded Side | 30.15 (29.43, 30.87) | 30.03 (29.29, 30.77) | 31.17 (30.44, 31.90) |

**Table 4.** *Cont.*

| Parameter | Backpack in Hand | Backpack on Shoulder | Without Backpack (Control Trial) |
|---|---|---|---|
| | Mean (95% CI) | Mean (95% CI) | Mean (95% CI) |
| **Single Support [%]** | | | |
| Unloaded Side | 30.38 (29.65, 31.11) | 29.84 (29.09, 30.59) | 31.18 (30.46, 31.91) |
| Loaded Side | 30.40 (29.68, 31.13) | 30.13 (29.37, 30.88) | 31.40 (30.61, 32.18) |
| **Double Support [%]** | | | |
| Unloaded Side | 39.46 (38.07, 40.85) | 40.31 (38.92, 41.71) | 37.43 (35.95, 38.91) |
| Loaded Side | 39.44 (38.04, 40.84) | 39.86 (38.39, 41.34) | 37.45 (35.97. 38.93) |
| **Gait Cycle [s]** | | | |
| Unloaded Side | 1.12 (1.08, 1.17) | 1.13 (1.09, 1.18) | 1.14 (1.09, 1.18) |
| Loaded Side | 1.12 (1.08, 1.17) | 1.13 (1.08, 1.17) | 1.14 (1.09, 1.18) |
| **Cadence [step/min]** | | | |
| Unloaded Side | 108.72 (104.49, 112.95) | 107.70 (103.62, 111.77) | 107.00 (103.21, 110.79) |
| Loaded Side | 108.61 (104.58, 112.65) | 108.21 (104.17, 112.26) | 107.07 (103.29, 110.84) |

### *3.2. Load Position Effect*

The statistically significant main effect of load position was found in all parameters: normalized step length ($F = 7.35$, $p = 0.001$, $\eta_p{}^2 = 0.16$), stance phase ($F = 40.25$, $p < 0.001$, $\eta_p{}^2 = 0.50$), swing phase ($F = 40.30$, $p < 0.001$, $\eta_p{}^2 = 0.50$), single support ($F = 33.93$, $p < 0.001$, $\eta_p{}^2 = 0.46$), double support ($F = 48.19$, $p < 0.001$, $\eta_p{}^2 = 0.55$), gait cycle ($F = 11.11$, $p < 0.001$, $\eta_p{}^2 = 0.21$) and cadence ($F = 17.81$, $p < 0.001$, $\eta_p{}^2 = 0.31$). Bonferroni post hoc analysis was used for further pairwise comparisons.

Step length was the shortest when the backpack was carried in the hand compared to the shoulder position ($p = 0.006$) and no load ($p = 0.003$). Gait cycle and cadence were the shortest and the greatest, respectively, when the backpack was carried in the hand compared to the shoulder position ($p = 0.002$) and no load ($p < 0.001$). There were no statistically significant differences between shoulder position and no load in all three of the above-mentioned parameters. The stance phase was the longest when the backpack was carried on the shoulder compared to the hand ($p = 0.009$) and no load ($p < 0.001$). However, single support was the longest without load compared to hand position ($p < 0.001$) and shoulder position ($p < 0.001$). Double support was the longest when the load was carried on the shoulder compared to hand position ($p = 0.003$) and no load ($p < 0.001$). The swing phase lasted the longest without load compared to the hand position ($p < 0.001$) and shoulder position ($p < 0.001$). Detailed results are presented in Tables 3 and 4.

### *3.3. Inclination and Load Position Interaction*

The statistically significant interaction of incline factor and load position was found in the stance phase ($F = 4.29$, $p = 0.02$, $\eta_p{}^2 = 0.10$), swing phase ($F = 4.18$, $p = 0.02$, $\eta_p{}^2 = 0.09$), gait cycle ($F = 12.67$, $p < 0.001$, $\eta_p{}^2 = 0.24$) and cadence ($F = 16.88$, $p < 0.001$, $\eta_p{}^2 = 0.30$). The interactions are graphically presented in Figure 3.

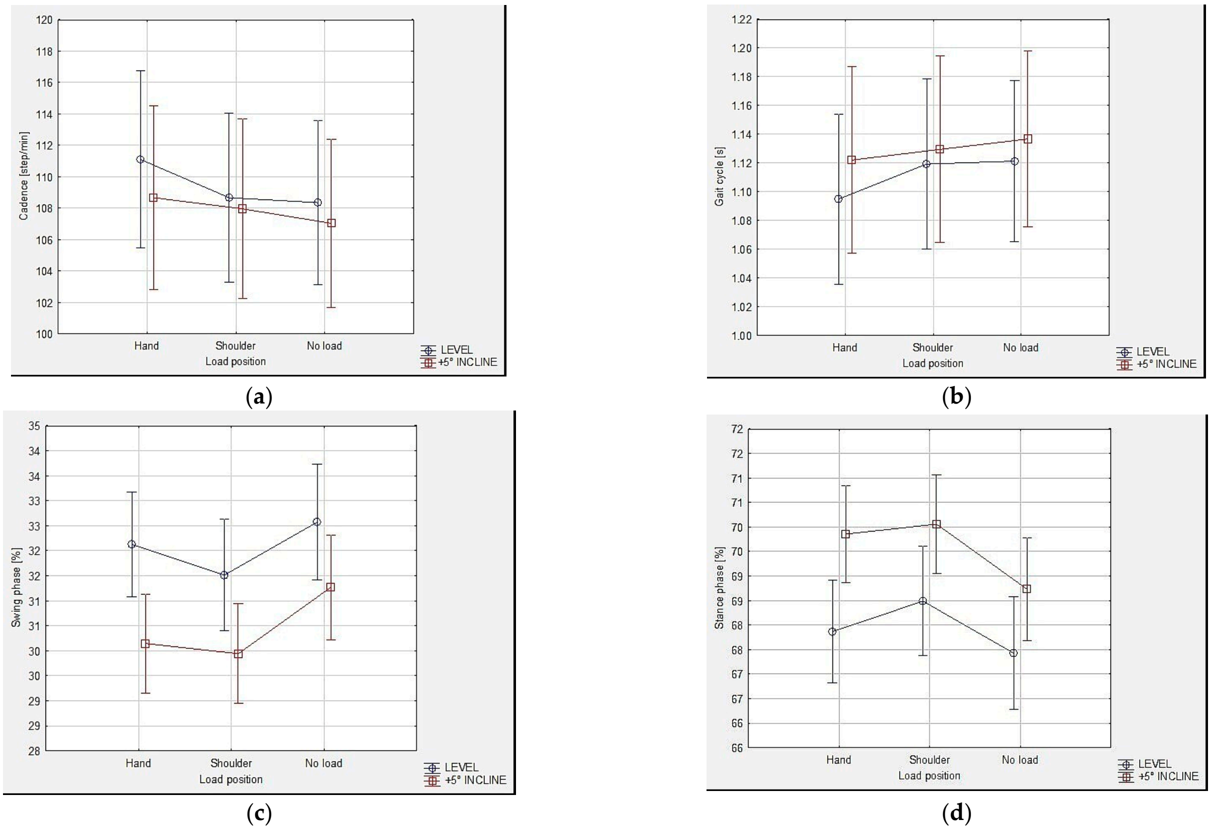


**Figure 3.** Plots show statistically significant ($p < 0.05$) interactions between inclination and load position. Vertical bars denote 0.95 confidence intervals and markers denote means: (**a**) cadence; (**b**) gait cycle; (**c**) swing phase; (**d**) stance phase.

The stance phase and swing phase were different ($p < 0.001$) when comparing level walking and uphill walking in all three load positions. There were no statistically significant differences in terms of stance phase between hand position and no load when participants walked on the level treadmill. There were also no differences in terms of swing phase between hand position and shoulder position when participants walked uphill. Other comparisons of stance and swing phases between trials of different load positions, apart from those mentioned earlier, were statistically significant ($p < 0.05$) (Figure 3).

The gait cycle and cadence were different ($p < 0.05$) when comparing level walking and uphill walking in all three load positions. There were no statistically significant differences in the gait cycle between the shoulder position and no load when participants walked on a level treadmill and with an incline. There were also no changes in terms of cadence between shoulder position and no load when participants walked on the level. The remaining comparisons of gait cycle and cadence between trials of different load positions, apart from those mentioned above, were statistically significant ($p < 0.05$) (Figure 3).

## 4. Discussion

Incline walking and load carriage are external factors that can alter spatiotemporal gait parameters. Both can be related to external stress on the musculoskeletal system, requiring adaptations of posture and movement patterns. Thus, the primary aim of this study was to assess how the incline of the treadmill and the position of the load affected walking while carrying a backpack asymmetrically. The main finding was that both factors, incline and load position, significantly affect spatiotemporal gait parameters, which is consistent with the stated hypothesis.

Current findings agree with previous studies on spatiotemporal gait patterns, which have reported that step length increases with increasing incline and cadence decreases uphill as the angle of incline increases. These results are likely linked to the fact that walking on an incline requires greater force exertion across the hip, knee, and ankle, as well as increased ankle movement [30]. Mexi et al. investigated level (0%) and uphill (5, 10 and 15%) walking at a speed of 5 km/h without and with a front pack or a backpack (15% of body weight). The main finding of Mexi et al.'s study was an interaction between inclination and backpack position for stride length and cadence, which is consistent with our findings [31]. In the current study, changes observed between slope and level walking were similar in all three conditions of load. However, there were some differences between load positions.

Previous studies reported that walking speed and cadence decreased significantly with increasing backpack load, while double support time increased. The demand for increased power at the lower limb joints increased with the amount of weight carried in the backpack [32]. Children also walked with a slower cadence with a load brought to school. Backpack carriage with different loads did have a significant effect on force distribution and plantar pressure [33]. Even when the load was light (4 kg), noticeable shifts in body posture and pressure distribution were detected when individuals carried weight asymmetrically using their hands [13]. The findings of Devroey et al. suggest that carrying loads of 10% of the body weight or more should be avoided, as these loads cause significant changes in electromyography, kinematics and subjective feelings of discomfort (Borg's rating scale) [24]. Our findings lead us to a similar conclusion; that 10% of the body weight can significantly affect gait parameters in both positions, in hand and on the shoulder. However, the speed was set at the beginning and was steady during trials, in contrast to previous studies [32,34]. For this reason, participants had to adapt their gait to maintain the pace. That can explain some differences between the current study and previous ones. Subjects carrying loads by their sides may increase their cadence and decrease their stride length in order to maintain velocity. We found that step length and gait cycle were the shortest and cadence was the greatest when the backpack was carried in hand compared to the shoulder position and no load. There were no statistically significant differences between shoulder position and no load. That implies that the lower position of the load may have affected these parameters.

Individuals can increase cadence and simultaneously decrease step length to maintain speed when carrying the load in hand for two reasons. Carrying a backpack in the hand and taking long steps can involve a large swing of the load, which is not so noticeable when the load is on the shoulder. Load swing is a perturbation and can affect balance during walking, and thus a reduction in step length is an adaptation to avoid balance disturbance [35]. Body balance is a crucial factor in maintaining safe locomotion and avoiding falls. A shorter step length is related to poor balance, which is a known indicator of physical disability [28]. Carrying a load in the hand lowers the center of mass. However, the load is further from body's center of mass compared to shoulder carrying [13].

A second possible explanation of our findings is a mechanism of increasing cadence while maintaining a consistent pace to lower impact forces [36,37]. The asymmetrical load carried in the hands alters pelvis stability and increases the activity of hip abductors contralateral to the load [38]. Thus, participants probably adapt their gait pattern to minimize acting forces and exertion. Previous studies suggest that healthy young individuals walk in a way that maximizes front–back and up–down stability while maintaining sufficient side-to-side stability [39].

With regard to the shoulder position of the load, the stance phase was the longest when the backpack was carried on the shoulder compared to the hand and no load, mainly because double support increased when the load was carried on the shoulder. The single support and swing phases were the longest without load compared to the two load positions. These findings suggest that gait cycle phases were more affected by the higher position of the load during walking. Gait changes observed due to increased double support are similar to changes due to decreasing walking speed [40]. Longer double support and stance phases also can improve stability [40].

A previous study showed that placing a load lower on the back affected the spatiotemporal parameters more than when loads were placed high on the back. The results regarding spatiotemporal parameters suggest that a decrease in walking speed and step rate, as well as an increase in time spent in a double support phase for a lower configuration, may act as a compensatory mechanism to reduce walking instability and mechanical strain on the musculoskeletal system [34]. Zwick et al. suggest that carrying asymmetric loads over short distances should include a shoulder carry technique, as gait parameters differ less from walking without a load than when carrying it in the hand [11]. In the current study, we cannot clearly define a better technique for carrying the load since both caused different adaptations. While shoulder carrying may have a greater impact on the swing and stance phases, hand carrying may have a greater impact on cadence and the gait cycle. According to a previous study, in patients with LBP, step length, stride length and speed are often altered, resulting in slower walking and increased double support subphases of stance [21]. Those alternations are similar to those observed during load carriage and can be indicators of an increased effort to maintain stability and safety.

Another important practical implication of our study is the effect of asymmetrical loading on the human gait. Abaraogu et al. investigated the influence of the type of backpack shoulder strap on gait parameters and the perceived exertion of young adults. They found that the carriage of a backpack either on a single strap (asymmetrically) or two straps does not appear to influence gait phases, but leads to increased perceived exertion [41]. However, the lateral position of the load can generate unstable conditions. The lack of stability in locomotion necessitated significant modifications to gait parameters in order to preserve stability. Additionally, high compression and shear forces exert more pressure on the lumbar–sacral spine when comparing the lateral position to other carrying methods [9]. Thus, previous studies recommended reducing the potential risks associated with load carrying, by using a symmetrical carrying method [9,10]. Although asymmetric weight affected gait parameters in our study, there were no differences between the loaded and non-loaded sides. However, daily lifting or carrying heavy objects may have negative effects on health, including poor body posture, back pain and increased oxygen consumption [42,43]. Asymmetrical loading with different load placements should be considered an important factor influencing the daily gait pattern, especially among students and professionals involved in manual handling. The relationship of incline walking to load carriage should be further investigated in terms of pain disorders and postural abnormalities.

A lack of comparisons between a few weight magnitudes or different inclinations can be considered a limitation of this study. It could be a starting point for future studies to investigate how asymmetrical loading affects gait patterns with increasing load and surface inclination. The device used in our study (OptoGait system), although previously used in similar studies [31], also has some limitations resulting from the optical method of data recording and its sensitivity to different walking speeds. Relatively small and homogeneous samples and controlled laboratory settings (treadmill walking) should also be mentioned as possible limitations. Thus, our findings might not accurately reflect real-world conditions and cannot be generalized to other populations.

## 5. Conclusions

Surface inclination and external load position significantly affected spatiotemporal gait patterns. However, load carriage in the hand affected mainly cadence, gait cycle length and step length, while the shoulder position of the load influenced the stance phase. Asymmetric loading with different load locations should be considered as an important factor influencing the day-to-day gait pattern. This relationship should be further investigated in terms of pain disorders and postural abnormalities. Future studies could explore the effects of different load weights, positions or inclines in more detail, or investigate the long-term impact of asymmetrical load carriage on the musculoskeletal system. Due to laboratory settings and homogenous samples, our findings might not accurately reflect real-world conditions and should be interpreted with caution and cannot be generalized to other populations.

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