Efectos de la inclination en Farmer´s Carry: propriedades musculares e fuerza

Effects of inclination in Farmer's Carry: muscle properties and strength

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Abstract

Introduction: The farmer's carry is a loaded-carry exercise in which an individual walks a distance while holding heavy loads in each hand, requiring substantial grip strength, whole-body stability, and coordinated lower-limb force production.
Objective: This study aimed to examine the acute effects of a light-load inclined farmer's carry protocol on grip strength, *rectus femoris* muscle mechanical properties, and lower-limb asymmetries.
Methodology: Twelve healthy young adults completed a continuous treadmill walk at 4 km/h while carrying two 10kg dumbbells, progressing through five incline stages (0–8%), each corresponding to 50 meters. Grip strength and muscle mechanical properties were recorded after each stage during a 1-minute rest.
Results: Significant grip strength reductions were observed in both hands, with decreases of 10.10% in the dominant side ($p < 0.05$, $\eta^2p = 0.61$) and 8.50% in the non-dominant side ($p < 0.05$, $\eta^2p = 0.41$). Also, a significant decrease in logarithmic decrement was detected in the dominant side ($p = 0.04$, $W = 0.19$). At baseline, 0, 2 and 6% were also observed significant differences between the dominant side and non-dominant side in logarithmic decrement. Conclusions: Overall, inclined farmer's carry efforts primarily induced peripheral, grip-specific fatigue, with minimal alterations in *rectus femoris* muscle mechanical properties, supporting the use of inclines to safely increase task difficulty without excessive mechanical stress.

Keywords

Farmer's carry; grip strength; incline walking; lower-limb asymmetry; muscle mechanical properties.

Resumen

Introducción: El farmer's carry es un ejercicio de transporte de cargas que requiere fuerza de prensión, estabilidad global y producción coordinada de fuerza de los miembros inferiores. Objetivo: Este estudio analizó los efectos agudos de un protocolo de farmer's carry inclinado con cargas ligeras sobre la fuerza de prensión manual, las propiedades mecánicas del recto femoral y las asimetrías de los miembros inferiores.
Metodología: Doce adultos jóvenes sanos realizaron una caminata en cinta rodante a 4 km/h transportando dos mancuernas de 10 kg. El protocolo incluyó cinco etapas de inclinación (0–8%), correspondientes a 50 metros cada una. Tras cada etapa, durante un descanso de 1 minuto, se evaluaron la fuerza de prensión y las propiedades mecánicas musculares.
Resultados: Se observaron reducciones significativas de la fuerza de prensión en ambas manos, con disminuciones del 10.10% en el lado dominante ($p < 0.05$; $\eta^2p = 0.61$) y del 8.50% en el lado no dominante ($p < 0.05$; $\eta^2p = 0.41$). También se detectó una disminución significativa del decremento logarítmico en el lado dominante ($p = 0.04$; $W = 0.19$). Además, se observaron diferencias entre ambos lados en baseline y en las inclinaciones de 0, 2 y 6%.
Conclusiones: El farmer's carry inclinado indujo principalmente fatiga periférica específica de la prensión, con mínimas alteraciones en las propiedades mecánicas del recto femoral, apoyando el uso de inclinaciones para aumentar la dificultad de la tarea sin excesivo estrés mecánico.

Palabras clave

Asimetría de miembros inferiores; caminata inclinada; fuerza de prensión; paseo del granjero; propiedades mecánicas musculares.

Introduction

Loaded carries constitute a subclass of resistance training (RT) exercises in which the athlete holds or transport an external load in one or both hands while moving or maintaining position. They emerge as a versatile strength option that bridges athletic performance, occupational demands, and clinical applications as they can enhance well-being, work capacity, and overall physical capability by directly targeting the mechanisms of load management and movement efficiency (Izquierdo et al., 2021; Wheelock et al., 2025). Loaded carries can be accomplished in multiple ways since various exercises and patterns exist, such as the farmer's carry (FC), zercher's carry, or the waiter's carry (Hindle et al., 2019), accordingly to the way that the weight is hold, if it is at the waist height, above head or in front of the body, among others.

The FC has become increasingly common in RT circuits (Struder et al., 2021), consisting of carrying a load in each hand while covering a predetermined distance, typically between 20 and 50 meters, at a fast pace (Keogh et al., 2014). However, depending on the intended training outcome, adjustments in movement velocity can also be applied (Ghigiarelli et al., 2013; Keogh et al., 2014; Winwood et al., 2015), as performing the FC requires substantial dynamic balance, grip strength (GS), stabilization, and upper-body strength, along with powerful simultaneous extensions of the hip, knee, and ankle during both the lifting and walking phases (Ghigiarelli et al., 2013; Keogh et al., 2014; Winwood et al., 2014; Woulfe et al., 2014).

As a sustained isometric contraction, GS determines not only the ability to hold the load but also the duration and quality of the exercise (Winwood et al., 2011). And, in the context of loaded carries, grip fatigue can become a limiting factor, influencing posture, gait mechanics, and the recruitment of compensatory muscle groups. GS is also widely recognized as a key indicator of overall muscular fitness and has been linked in research to athletic performance, and long-term health outcomes (Szaflik et al., 2025). Understanding the contribution of GS to FC performance is therefore essential for optimizing training protocols and assessing individual capacity.

Beyond its substantial GS requirement, the FC relies heavily on the lower limb, as the task demands powerful and continuous contributions from the ankle, knee, and hip extensors to maintain dynamic balance and move under load (Keogh et al., 2014). During the FC, muscles must maintain tension over time while also responding to the cyclical demands of gait. This combination of isometric and dynamic loading creates a distinctive mechanical environment that can reveal important insights into neuromuscular function.

In the sports context, such as Strongman competitions, the FC is mostly performed on a flat and predictable surface. However, in daily-living tasks this scenario rarely applies, due to the irregularities of the terrain and specific constraints of the environment. Inclined walking differs markedly from ground-level walking, with inclines and declines altering joint kinematics and kinetics (Pickle et al., 2016), modifying centre-of-mass trajectory and ground reaction forces, and consequently influencing how external loads are stabilized. For example, uphill walking might increase the demand on lower-limb extensors, while downhill walking might emphasize eccentric control of knee and ankle musculature. These biomechanical changes can also be used intentionally to influence gait patterns, as stride length or stride rate may be adjusted either through deliberate gait modification, by manipulating task constraints, or by introducing subtle variations in surface incline (Keogh et al., 2014).

McGill et al. (2009) evaluated muscle electromyographic and kinematic data using a detailed torso model to estimate back load, lumbar stiffness, and hip torque, and found that peak activation of the abdominals and *rectus femoris* (RF) occurred during walking, while the latissimus dorsi and thoracic and lumbar erector spinae peaked during lifting. Also, that *gluteus medius* muscle activation varied with experience with less skilled athletes peaking during the lift, whereas more skilled athletes peaked during the first step. And, that peak lumbar flexion and twist occurred during lifting and first-step phases, with angles of 33.90 ± 3.80°, 3.60 ± 0.80°, and 8.20 ± 0.40°, respectively. More recently, Ellestad et al. (2024) evaluated the muscle activity of the *rectus abdominis*, *obliquus externus abdominis*, *longissimus thoracis*, and *multifidus* during the FC and other exercises, reporting a lower activation in the *rectus abdominis* when compared to the other muscles, at the right (10.70 ± 2.10 %MVC) and left (8.40 ± 0.80%MVC) side and a highest at in the right side in the *longissimus thoracis* (16.40 ± 1,80%MVC) and in the *multifidus* (16.30 ± 2.20%MVC).

Keogh et al. (2014) aimed to identify preliminary kinematic characteristics of the 20m FC and compare fastest and slowest performances, and found greater velocity (3.29 ± 0.38; 3.15 ± 0.32 m/s), stride length (1.67 ± 0.10; 1.62 ± 0.16 m) and stride rate (1.97 ± 0.13; 1.93 ± 0.12 m/s), and reduced ground contact time (0.30 ± 0.03; 0.30 ± 0.04 s) in the 8.5–11.5 m and 17–20 m stages compared to 0–3 m with the fastest trials showing greater velocity, stride length, stride rate, and lower contact time. Which was supported by Hindle et al. (2019) that reported that the athletes who perform better in the FC and heavy sled pull typically show greater stride length, higher stride rate, and reduced ground contact time, reflecting more efficient and powerful locomotion mechanics.

Although the FC is typically performed on flat and predictable surfaces, real-world environments often involve inclines or uneven terrain, which are known to alter gait mechanics, joint loading, centre-of-mass behaviour, and muscular demands. These biomechanical changes may meaningfully influence GS, which determines the ability to sustain load carriage, and the mechanical properties of lower-limb musculature, particularly the RF, which contributes to propulsion and postural control under load. Furthermore, loaded carries are inherently asymmetrical tasks, as even small differences in limb dominance or load distribution can influence gait patterns, stabilization strategies, and fatigue profiles, which could result in injurie, enhancing the importance of studying this subject.

Therefore, the aim of this study is to evaluate the acute effects of a light-load inclined FC protocol on GS, RF muscle mechanical properties, and lower-limb asymmetries. We hypothesized that (i) the strength of GS decline would exceed the amount of change in RF mechanical properties, and that (ii) the inclined protocol would generate detectable side-to-side asymmetries in RF mechanical properties and GS.

Method

We employed a within-subject repeated measures design to evaluate the effects of incline on muscular performance during a loaded carry protocol. All participants completed a single laboratory visit during which the same procedures were followed. Prior to testing, the participants were informed of the procedures and signed an institutionally approved written informed consent. This study was approved by the University Ethics Committee (N.39-2025ESDRM), and all the procedures were in accordance with the Declaration of Helsinki regarding human research.

Participants

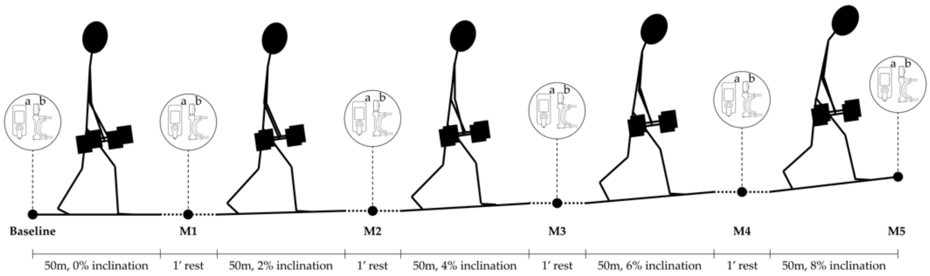
Twelve healthy young adults (21.4 ± 2.9 years, 172.0 ± 5.0 cm, 71.2 ± 7.7 kg, 23.8 ± 1.9 kg/m^2, 75% right-sided dominant), university students in sports sciences, took part in the study. Subjects were excluded if they had (i) injuries to their lower/upper extremity that limited their physical activity in the past 6 months; (ii) surgery on lower/upper extremity in the past 12 months; (iii) a medical condition that would affect their ability to perform the test correctly; (iv) taken medication that could impact their strength (Habets et al., 2018).

Procedures

Upon arrival, anthropometric data were collected, including age, height, weight, body mass index, and identification of the dominant limb. Then, previously to the test, each subject performed a 5 min of warming-up at 100 watts and 60 revolutions per minute on a cycle ergometer (Parraça et al., 2022), to promote muscle activation and prepare the cardiorespiratory system for the subsequent effort.

The load carriage protocol involved a continuous treadmill walk at a speed of 4 km/h while participants performed the FC exercise carrying two 10 kg dumbbells (one in each hand). The protocol was structured into five sequential incline stages: 0, 2, 4, 6, and 8%, with each stage corresponding to a distance of 50 meters (Figure 1). At the conclusion of each incline segment, GS and muscle mechanical properties were reassessed using the same standardized procedures during a 1-minute rest.

Figure 1. Schematic illustration of the load carriage protocol. a, Jamar Digital Hand Dynamometer; b, MyotonPRO.



Instruments

GS was measured at both hands for each participant using a calibrated dynamometer (Jamar Digital Hand Dynamometer, Jamar® PLUS). Participants were instructed to squeeze the dynamometer as hard as possible while maintaining the shoulder at approximately 90° of flexion and the elbow fully extended, avoiding any additional body movement, during the test three measurements were recorded, and the average was further calculated.

Muscle mechanical properties were assessed at baseline and post-tests, with MyotonPRO (Myoton AS, Estonia), a non-invasive digital palpation device, which applied mechanical impulses to the skin (during 15 ms with an intensity of 0.4 N) under a pre-compression force of 0.18 N on the tissue layer of interest to minimize signal bias from soft tissue overlying muscle and tendon. The device was held perpendicular ± 5° to the skin and the impulses cause damped oscillations of the underlying tissues, which are recorded as parameters for tone (Hz), stiffness (N/m), and elasticity (Logarithmic Decrement) (Sohirad et al., 2017; Szajkowski et al., 2026). The required pre-compression force was reached when the signal light transitions from orange to green, triggering the automatic delivery of the programmed impulses. The MyotonPRO device recorded the Coefficient of Variation (CV) between the five different mechanical impulses per measurement and displays this as a percentage next to each parameter. In the present study a threshold of 3% CV was set, if any parameters were over this threshold the measurement was repeated (Van Deun et al., 2018). The anatomical measurement points were marked with the participant lying on a gurney at full relaxation. The RF muscle measurement point was located at 1/3 of the distance (from the patella) in a line formed between the superior border of the patella and the iliac spine. For the MyotonPRO recordings, two sets of 5 impulses were applied, and a mean of the 10 pulses was taken and used in the analysis (Van Deun et al., 2018).

Data analysis

Statistical analysis was conducted using the Statistical Package for the Social Sciences (SPSS, Version 25, IBM SPSS, Armonk, NY, USA) software. Descriptive statistics (Mean ± SD) were reported, and the data distribution was assessed using the Shapiro-Wilk normality test. An ANOVA of repeated measures was performed to compare the effect between conditions when the normality was verified, and the Friedman's test was performed when the normality was not verified. Sphericity was evaluated using Mauchly's test, and when the assumption was violated, Greenhouse–Geisser–corrected values were used. The differences between sides were assessed using paired samples t-test when the normality was verified and the Wilcoxon signed-rank test was performed when the normality was not verified. The magnitude of the difference was assessed between conditions considering the effect size index, using the partial eta square (η^2P) for normality-assumed distributions and interpreted as: (i) small effect if $\eta^2P \approx 0.02$; (ii) medium effect if $\eta^2P \approx 0.13$; (iii) large effect if $\eta^2P \approx 0.26$ (Cohen, 1988). Kendall's coefficient of concordance (W) was calculated as an effect size measure, when the normality was not verified, and interpreted as: (i) small effect if W ≈ 0.10; (ii) medium effect if W ≈ 0.30; (iii) large effect if W ≈ 0.50. In addition to the inferential statistical analysis, indicators of variability and percentage impact were calculated. Fatigue-induced performance loss was determined based on the percentage variation between the baseline value and the post-fatigue value. The statistical analysis was carried out for $p = 0.05$.

Results

Table 1 demonstrated the values observed at baseline and post-intervention. Were observed significant differences with a large effect size in GS on both hands with a decreasing in strength of 10.10% at the DS ($p < 0.05$, $\eta^2P = 0.61$) and 8.50% at the NDS ($p < 0.05$, $\eta^2P = 0.41$). Also, there were found significant differences with a small effect size in logarithmic decrement at the DS ($p = 0.04$, W = 0.19) with a decreasing of 5.59%. There weren't found significant differences on the other variables and the differences between baseline and post-intervention ranged from -2.23% to 1.75%.

Table 1. Baseline and post-intervention values with within-group changes, percentage differences, test statistics, p-values, and effect sizes for grip strength and muscle mechanical properties.

	Baseline (Mean ± SD)	Post Intervention (Mean ± SD)	Within-Group Changes (Mean ± SD)	Difference (%)	Test Statistic	p value	Effect Size
Grip strength (kg) $^{\alpha}$							
DS	42.58 ± 8.22	38.28 ± 6.07	-4.30 ± 3.00	-10.10	17.44	<0.01*	0.61
NDS	42.14 ± 6.90	38.56 ± 5.89	-3.58 ± 2.83	-8.50	7.65	<0.01*	0.41
Muscle mechanical properties							
Frequency (Hz) $^{\alpha}$							
DS	14.07 ± 0.38	14.29 ± 0.68	0.21 ± 0.58	1.56	0.98	0.48	0.08
NDS	14.22 ± 0.67	14.14 ± 0.62	-0.08 ± 0.55	-0.56	1.11	0.37	0.09
Stiffness (N/m) $^{\alpha}$							
DS	265.63 ± 13.90	270.27 ± 16.97	4.64 ± 16.78	1.75	0.67	0.53	0.06
NDS	271.55 ± 20.01	270.38 ± 17.03	-1.17 ± 17.88	-0.43	0.53	0.75	0.05
Logarithmic decrement $^{\beta}$							
DS	1.43 ± 0.29	1.35 ± 0.33	-0.08 ± 0.12	-5.59	11.39	0.04*	0.19
NDS	1.52 ± 0.26	1.49 ± 0.24	-0.03 ± 0.14	-1.97	4.94	0.42	0.08
Relaxation (ms) $^{\beta}$							
DS	19.31 ± 1.00	18.88 ± 1.17	-0.43 ± 1.06	-2.23	6.06	0.30	0.10
NDS	18.93 ± 1.58	18.93 ± 1.05	0.01 ± 0.98	0.00	6.54	0.26	0.11
Creep $^{\beta}$							
DS	1.33 ± 0.32	1.31 ± 0.33	-0.03 ± 0.06	-1.50	3.39	0.64	0.06
NDS	1.31 ± 0.34	1.30 ± 0.33	-0.01 ± 0.05	-0.76	1.78	0.88	0.03

*, significant differences, $p < 0.05$; $^{\alpha}$, assessed with repeated-measures ANOVA; $^{\beta}$, assessed with Friedman's test and Kendall's W (effect size).

Figure 1 illustrated the decreasing pattern in GS in the DS and NDS. The values observed at baseline and after 0% inclination are similar and afterwards it tends do decrease. There weren't found significant differences between the DS and NDS at any moment.

Figure 1. Grip strength assessed at baseline, and after 0, 2, 4, 6 and 8% inclinations. ■, domionant-side; ▨, non-dominat side.

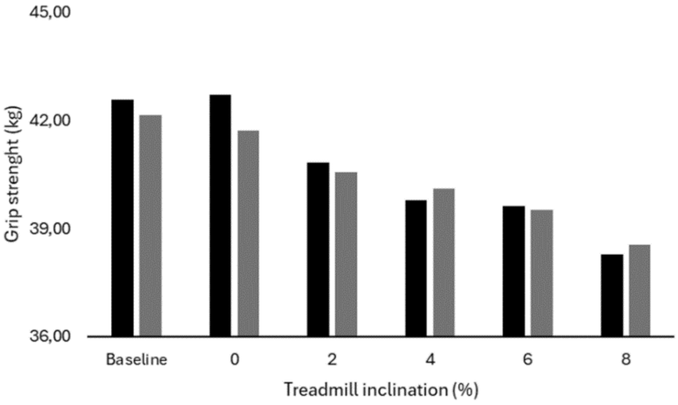
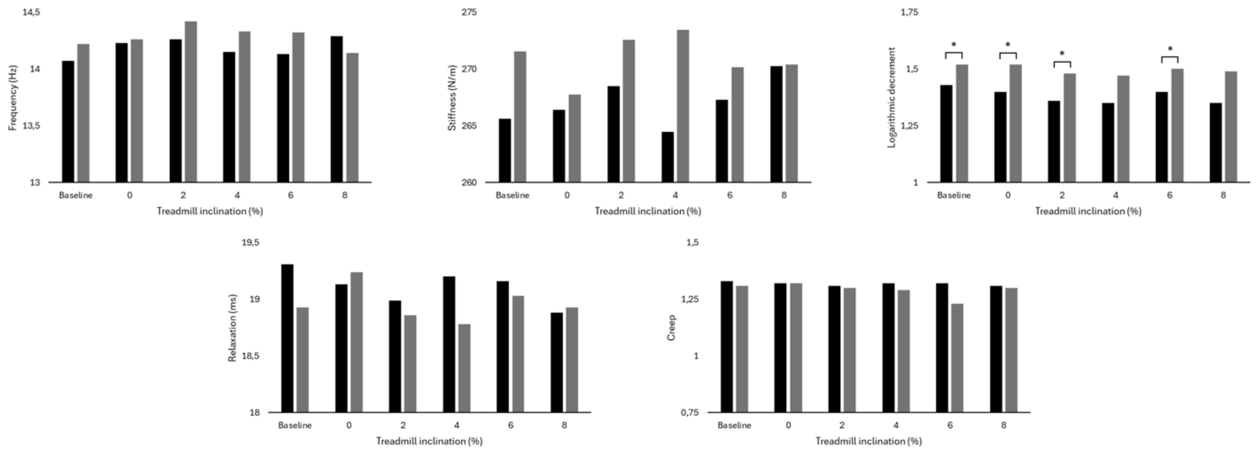


Figure 2 illustrated the values of muscle mechanical properties in the DS and NDS. The observed values at the different variables of the muscle mechanical properties didn't present an apparently pattern. There were found significant differences between the DS and NDS in the logarithmic decrement at baseline ($p = 0.02$), after 0% inclination ($p = 0.03$), after 2% inclination ($p = 0.04$), and after 6% inclination

(p = 0.03). There also appears to be a trend toward significance at 8% ($p < 0.10$), contrasting the other variables, which showed no meaningful differences.

Figure 2. Rectus femoris muscle mechanical properties assessed at baseline, after 0, 2, 4, 6 and 8% inclinations. ■, domionant-side; ▨, non-dominat side.



Discussion

The main aim of this study was to evaluate the acute effects of a light-load inclined FC protocol on GS, RF muscle mechanical properties, and lower limb asymmetries. The main findings of this study were: (i) the amount of GS decline exceeded the amount of change in RF muscle mechanical properties, reflecting the FC's strong reliance on sustained isometric grip; (ii) the inclined protocol generated detectable side-to-side asymmetries in RF mechanical properties. All hypotheses were fully confirmed.

There was a decreasing in GS as expected, due to the fatigue induced trough the stages of the protocol.

The results demonstrated a clear decline in GS for both the DS and NDS, with reductions of 10.10% and 8.50%, respectively, accompanied by large effect sizes. This decline aligns with previous literature describing the FC as a task highly dependent on sustained isometric grip demands (Winwood et al., 2011), where grip fatigue progressively limits load control, gait mechanics, and overall performance.

The observed GS reductions are consistent with the neuromuscular requirements described in prior biomechanical analyses. McGill et al. (2009) showed that the FC imposes substantial activation of trunk and hip musculature, particularly during the lifting and early gait phases, while Ellestad et al. (2024) reported relatively low activation of the *rectus abdominis* but higher activation of the *longissimus thoracis* and *multifidus*. These findings suggest that as GS fatigue accumulates, compensatory trunk stabilization demands may increase, potentially altering load-carrying mechanics. However, in the present study, no significant changes were observed in muscle mechanical properties such as frequency, stiffness, relaxation, or creep, indicating that the acute fatigue induced by the protocol was primarily peripheral rather than affecting the mechanical behaviour of the assessed musculature.

A small but significant reduction (−5.59%) in logarithmic decrement was observed in the DS, suggesting a slight improvement in muscle elasticity or reduced damping. This isolated finding contrasts with the absence of meaningful changes in the remaining mechanical variables, reinforcing that the intervention did not substantially alter muscle viscoelastic properties.

The lack of significant changes across inclinations in most mechanical variables also suggests that the imposed task constraints while sufficient to induce GS fatigue were not demanding enough to elicit measurable alterations in muscle tone or stiffness. This is consistent with previous studies showing that FC performance is more sensitive to spatiotemporal gait adaptations (Keogh et al., 2014; Hindle et al., 2019) than to acute changes in muscle mechanical behaviour. Indeed, athletes who perform better in loaded carries typically exhibit greater stride length, stride rate, and reduced ground contact time, reflecting efficient locomotor strategies rather than changes in intrinsic muscle properties (Keogh et al., 2014; Hindle et al., 2019).

Generally, the findings indicate that repeated FC efforts under varying inclinations primarily induce grip-specific fatigue, without substantially affecting the mechanical properties of the assessed musculature. This knowledge reinforces the central role of GS as a limiting factor in loaded-carry performance and highlights the importance of incorporating grip-endurance strategies into training programs involving FC or similar tasks.

Several limitations should be considered when interpreting the findings of this study, namely: i) the sample size was relatively small, which may limit the generalizability of the results and reduce statistical power for detecting subtle changes in muscle mechanical properties; ii) only acute responses were examined; therefore, the results reflect short term fatigue rather than long term adaptations to loaded carry training; iii) the analysis of a single muscle group for mechanical properties, which may not fully represent the complex neuromuscular demands of the FC, particularly at the trunk and lower limbs; iv) the manipulation of inclinations in the treadmill, the load remained constant, preventing analysis of potential interactions between load magnitude and slope; v) finally, the study relied on surface based mechanical assessments rather than electromyography or motion analysis, which could have provided deeper insight into compensatory strategies and movement adaptations.

Future research should explore the effects of different load magnitudes, distances, and incline profiles to better understand how these variables interact to influence fatigue and neuromuscular responses. Incorporating electromyography, motion capture, and force plate analysis would provide a more comprehensive understanding of compensatory strategies and biomechanical adaptations during loaded carries. Longitudinal studies are needed to determine whether repeated exposure to incline based carries leads to chronic adaptations in GS, muscle mechanical properties, or gait mechanics. Additionally, examining populations with varying training backgrounds such as untrained individuals, tactical personnel, or elite strongman athletes may reveal important differences in fatigue resistance and movement strategies. Lastly, exploring sex-based differences and the role of psychological factors such as perceived exertion could further enrich the understanding of loaded carry performance.

The findings highlight the central role of GS in loaded carry performance, demonstrating that even moderate inclines can induce meaningful grip fatigue without substantially altering muscle mechanical properties. Coaches and practitioners should therefore prioritize GS training when preparing athletes for tasks involving FC or similar load transport activities. Because fatigue accumulated similarly in both hands, bilateral GS conditioning may be more beneficial than unilateral approaches. The absence of significant changes in muscle mechanical properties suggests that inclines can be used to increase task difficulty without imposing excessive mechanical stress on the assessed musculature, preventing injuries and making them a safe progression strategy. These insights may also inform occupational settings where load carriage is common, helping to optimize task design and reduce fatigue related performance decline.

Conclusions

This study demonstrated that repeated FC efforts performed under varying inclinations primarily induce significant GS fatigue, with reductions of 10.10% in the DS and 8.50% in the NDS. In contrast, muscle mechanical properties showed minimal changes, with only a small decrease in logarithmic decrement observed in the dominant side. We can conclude that the acute demands of incline based loaded carries are largely peripheral and grip specific, rather than altering the viscoelastic behaviour of the assessed musculature. Overall, the results reinforce the importance of grip endurance in loaded carry performance and support the use of inclines as a safe method to increase task difficulty without imposing excessive mechanical stress.

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